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800G DR8 Transceiver Based on Thin-film Lithium Niobate Photonic Integrated Circuits

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Abstract *We demonstrate a fully functional 800G DR8 OSFP transceiver based on thin-film lithium niobate photonic integrated circuits. The transceiver achieves TDECQ below 2.5 dB, and ER above 5 dB. Total transceiver power consumption is achieved around 14.2 Watts at 70 degree Celsius ambient temperature.* *©2022 The Author(s)*

Introduction

In recent years, due to the exponential growth of data traffic, the demand for data capacity has increased substantially. As a result, the development of high-speed transceiver technology has received great interest within the community. In 2017, with the advent of IEEE Standard 802.3bs, management parameters including 100Gb/s, 400Gb/s and 800Gb/s have been specified, which became important guidelines for data center applications. Because of the increasing demand of computing capability, it has become a great challenge for data centers to continue operating with reduced cost, insertion loss and more importantly, lower power consumption [1]. Various approaches targeted at solving this problem have already been investigated over the past years. To optimize the Intra-datacenter connectivity, as one of the most important parts of the transmitter, many kinds of modulators have been studied widely. Directly modulated lasers (DMLs) have advantages such as a small form factor and lower cost, but at the same time suffer from bandwidth and chirping limitation [2]. Even with better digital signal processing (DSP) chips, the data rate and transmission distance are still limited. The electro-absorption modulators (EAM) and silicon Mach-Zehnder modulators (MZM) are probably better options for >100Gbps per channel applications. Integrated EAMs are widely used these days, while the users have to live with its relatively high cost, from both the EAM chip itself and the required TEC's for EAMs to work properly [3]. Silicon photonics (SiPh) MZM is another intriguing option, while the loss and limited bandwidth are two limiting factors. The waveguide loss of a typical SiPh MZM modulator, not including facet coupling loss or modulation loss, lies between 3-6 dB. This indicates that practically a DR4 module would need two high-power CW lasers instead of one, which translates to a considerable power consumption. Another limitation of SiPh MZM is its modulation bandwidth [4-6]. Commercial SiPh modulators normally have a bandwidth of 40GHz or below.

Recent research shows that thin-film lithium niobate (TFLN) modulator provides a promising combination of large bandwidth, low insertion loss and low driving voltage. It inherits most of the merits from bulk lithium niobate modulators, while providing much lower driving voltage and much smaller form-factor [7].

In this work, we demonstrate a fully functional TFLN modulator based 800 Gb/s transceiver. The transceiver complies with 400GBASE-DR4 standards and OSFP form factor requirements. This 8*100G transceiver is comprised of a pair of 400G TFLN modulator (100Gb/s per lane) transmitter sub-assemblies (TOSA) and a pair of receiver sub-assemblies (ROSA).

TFLN Modulator Design and Packaging

Within each optical sub-assembly, a 1310nm CW laser diode is coupled into a four-channel TFLN photonic integrated circuit (PIC), and the four output waveguides are coupled into a fiber-array pigtail. RF and DC biases are supplied to the TFLN PIC.

Four MZ modulators are integrated on the PIC, along with MMI-based splitters, spot-size converters, and gratings for power monitoring purpose. Within each MZM modulator, a single-ended traveling wave electrode is used for push-pull modulation, and thermal electrode is integrated for DC phase control, 50-Ohm load is also integrated. The sole optical input and four output ports are on the same side of the PIC.

The folded modulator design of each channel is deployed to minimize the chip area. Spot-size converters (SSC) are integrated at both input and output ports in order to reduce the coupling loss from the laser diode and the fiber array (FA). The coupling efficiency is measured to be 1-2 dB per facet.

optical components including TFLN chips. TFLN chips have gone through 2000 hours of damp heat reliability test according to Telcordia GR-468.

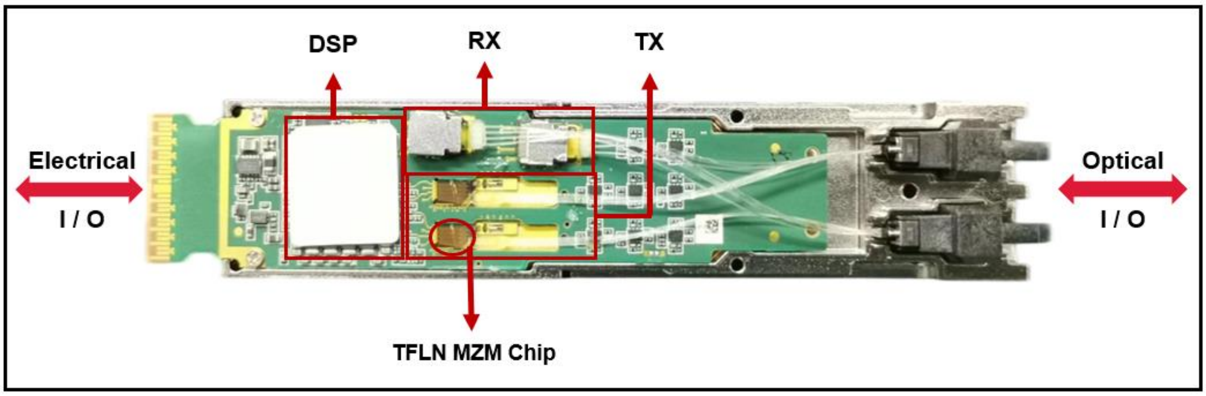

Fig. 2: The picture of the 800G DR8 OSFP module layout.

The device is fabricated from Ori-Chip's dedicated TFLN fab. The four-channel TFLN PIC is fabricated on a full 4-inch x-cut thin-film lithium niobate (TFLN) wafer with a 4.7-um-thick SiO_2 buffer layer and a high-resistance silicon substrate. Device pattern is defined by the technique of standard DUV photolithography. In order to reduce IL, photolithography and fluorine-based ICP dry etching processes are carefully optimized. As a result, waveguides with straight and smooth sidewalls are obtained with a propagation loss of about 0.26 dB/cm. The IL of each channel is measured to be around 13.5 dB, in which 7 dB is from the splitting and waveguide loss, 3.5 dB is from fiber coupling loss from both facets and 3dB is from the inherent modulation loss.

In order to measure V_π, a 1kHz triangle wave with 10V $V_{p\text{-}p}$ is applied on the traveling wave electrode (TWE) and the output light is collected by a PD. Then V_π is measured to be 2.4 V and based on the 8400-μm electrode length, $V_\pi L$ is determined to be 2 V·cm.

The small signal electro-optical (EO) response of the modulator is measured by a Vector Network Analyzer (VNA) with frequency sweeping from 100MHz to 50GHz. As shown in Fig.1, the 40GHz 3dB bandwidth is achieved and less than -10dB return loss of the RF signal across almost the entire spectrum is observed.

Due to the low IL, each 17-dBm CW laser is able to support four channels. Even at 70 degrees Celsius, 2dBm of output power per channel can be achieved, which meets requirements of IEEE 802.3-2018. The 8-channel transceiver is able to operate with only two continuous wave (CW) lasers, which saves two continuous wave (CW) lasers and therefore saves half of the number of lasers, fiber and lens components compared to its counterpart utilizing silicon photonics technology.

Non-hermetic packaging is deployed for all

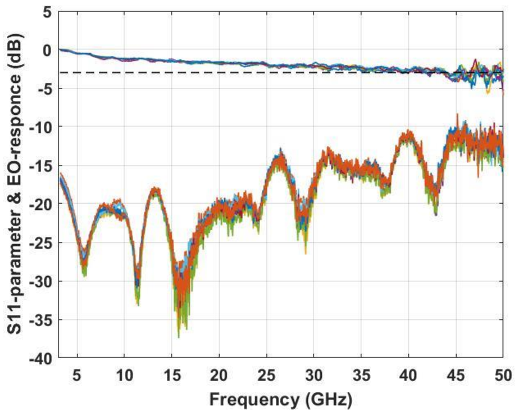

Fig. 1: The small signal EO-response and S11 of the TFLN modulator.

Transceiver Structure and Performance

A picture of the 800G DR8 OSFP transceiver layout is shown in Fig.2. In this transceiver, an 800G 7-nm PAM4 DSP is used with integrated modulator driver, which supports direct-driver with 1.5V $V_{p\text{-}p}$ single-ended.

By using TFLN modulator and integrated driver, the power consumption of the OSFP module is 14.21 Watts with 3.47 V input voltage at 70 degrees Celsius case temperature. The power consumption is 1.0 Watt lower compared to the 800G similar transceiver integrated with SiPh modulators.

Figure 3 shows clear open eye patterns of eight channels at 1.5V $V_{p\text{-}p}$ driving voltage under 53.125 Gbaud PAM-4 modulation. ERs of Channels 1-8 are 5.16dB, 5.07dB, 5.36dB, 4.54dB, 5.76dB, 5.08dB, 4.76dB, 5.06dB, respectively. TDECQs of Channels 1-8 are 2.05dB, 2.48dB, 2.04dB, 2.10dB, 1.99dB, 1.88dB, 2.25dB, 1.68dB, respectively.

Figure 4 shows the BER curves of eight channels with 0km and 10km fibers. The RX sensitivity of 1-8 channels is around -9dBm @2.4E-04.

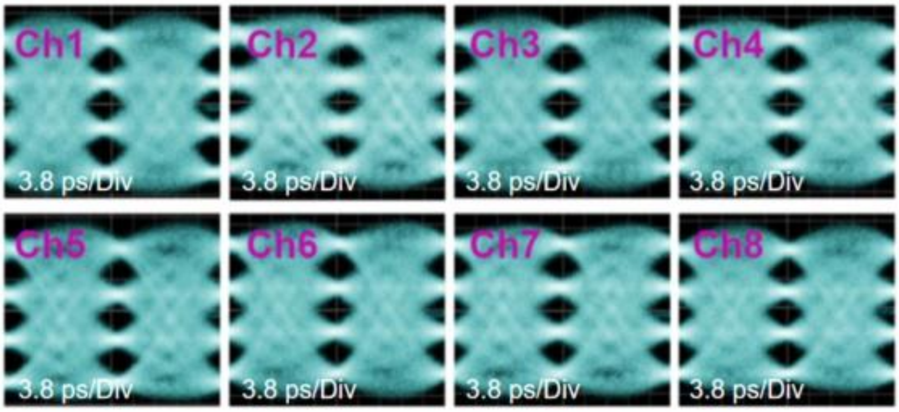

Fig. 3: 53.125 Gbaud PAM-4 eye diagrams of channel 1-8 at 1.5 V Vp-p driving voltage

Conclusions

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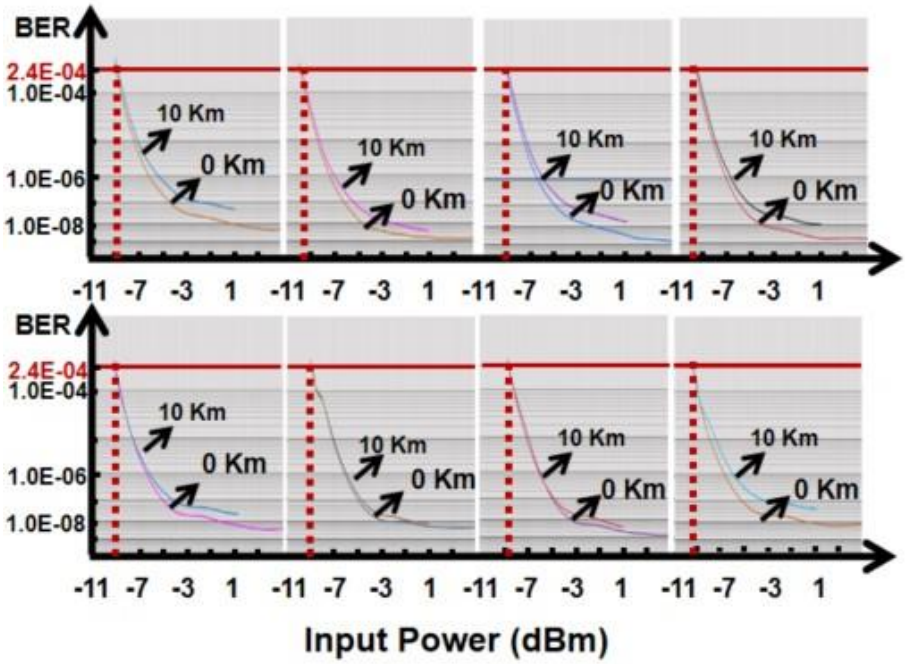

Fig. 4: BER curves with 0Km and 10Km fiber of channel 1-8

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