800 Gbps Fully Integrated Silicon Photonics Transmitter for Data Center Applications

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Abstract: A fully integrated 800 Gbps PAM-4 2×FR4 and DR8 silicon photonics transmitter with eight heterogeneously integrated DFB lasers is demonstrated for data center applications over a temperature range of 0~70°C and a reach of up to 2 km.
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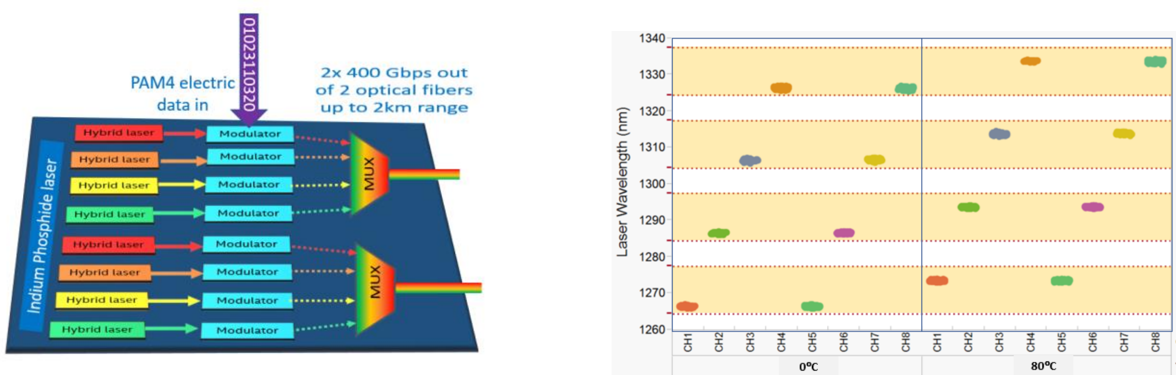
1. Introduction

With the continued strong data traffic growth in recent years, data center connections are now transitioning from 200G and 400G to 800G, and silicon photonics continues to be a key enabling technology to meet the requirements of high-speed connectivity between servers and switches within data centers. Silicon photonics with fully integrated optics (including lasers) has been successfully deployed in data centers for 100G PSM4, CWDM4, and 400G DR4/FR4 due to its scalability, leveraging the advantage of silicon manufacturing and wafer level test [2][3]. In this paper, we continue the scaling of our silicon photonics platform to 800G, and successfully demonstrate the industry's first fully integrated 8×100 Gbps PAM-4 2×FR4 and DR8 silicon photonics transmitter (Tx) for 800G applications over a temperature range from 0°C to 70°C and a reach of up to 2 km with excellent reliability.

2. Experiments and results

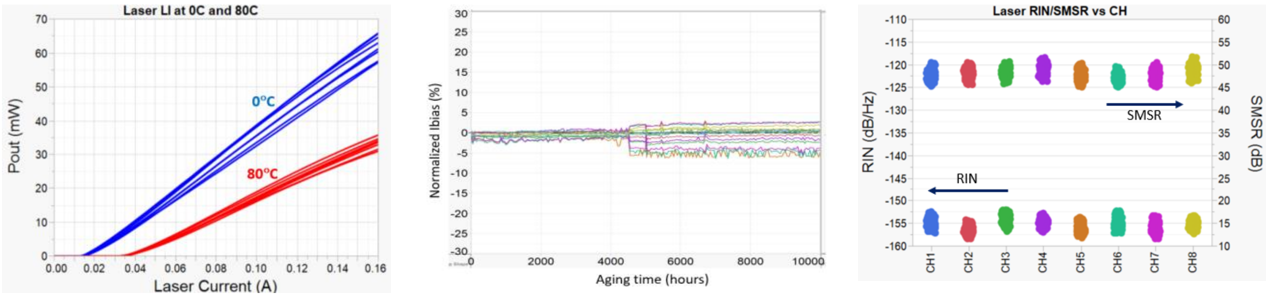
The 8×100 Gbps 2×FR4 silicon photonics Tx with heterogeneously integrated distributed feedback (DFB) lasers (1271, 1291, 1311 and 1331nm), 100 Gbps traveling wave Mach-Zehnder Interferometer modulators (TWMZM) and wavelength multiplexers (MUX) are depicted in Fig. 1(a). The 8×100Gbps DR8 Tx with 8×1311nm DFB lasers is also built on the same Tx architecture by excluding the MUX. These optical components and other photonic passive devices are fabricated using Intel's 300 mm heterogeneous integration process as described in previous work [1]. Fig. 1(b) shows the accurate targeting of 8 channels of 4-λ wavelength across the whole data center application temperature range of 0°C to 80°C with tight distribution (a standard deviation of 0.3 nm) on a 300 mm wafer. This is enabled by robust laser design and tight process control.



(a) (b)

Figure 1: (a) Illustration of 2×FR4 transmitter with 2×400Gbps data paths, (b) 2×FR4 transmitter center wavelength with upper spec limit (USL) and low spec limit (LSL) (dotted lines) from 0°C to 80°C chip temperature across 300 mm wafer.

Fig. 2(a) illustrates a typical Light-Current characteristic for 8 channels of 4-λ wavelength of III/V-Si Hybrid DFB lasers in 2×FR4 Tx. All 8 channels of laser output power (median values) exceed 30 mW at 80C° with no sign of thermal rollover. The power performance of these hybrid lasers, where light is already coupled to the silicon waveguide with nearly zero coupling loss, compares favorably to discrete lasers fabricated on native InP substrate and is crucial for transceiver products of 800G and beyond to have sufficient link budget. The accurate wavelength control combined with superior laser power performance up to 80°C chip temperature enables the uncooled operation of 2×FR4 and DR8 transmitters across the module temperature range of 0°C to 70°C.



(a) (b) (c)

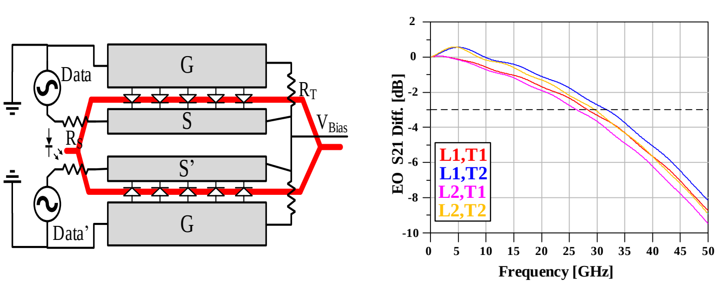
Figure 2: (a) Light (coupled in the Silicon Waveguide) versus Current characteristics of 8 channels III/V-Si DFB laser from 0°C to 80°C,(b) Relative drift of bias current required for 800G laser operating power with lasers stressed at a condition of 80°C/170mA for 10k hours, (c) 2x FR4 transmitter average RIN distribution and SMSR distribution at 0°C across 300 mm wafer

This platform of heterogeneously integrated III/V-Si hybrid laser has demonstrated excellent laser reliability performance in 100G CWDM4 and 400G DR4 transmitter products [2][3]. With twice the number of laser channels than DR4, reliability is more of challenge for 2×FR4 and DR8 Tx. Fig. 2(b) shows the HTOL (high temperature operation life) performance of III/V-Si hybrid laser showing stable bias current to produce the required operating power for lasers used in 2×FR4 or DR8 Tx after being stressed at a temperature of 80°C with a stress current of 170 mA for 10,000 hours up to date. These results, coupled with other accelerated aging test results ran at 150°C and 150mA, show that the lasers can well meet the reliability and life-time requirements for 800G applications.

The stability and spectral integrity of this 2×FR4 Tx are characterized at 0°C which is generally the worst-case operating condition for the key performance parameters such as relative intensity noise (RIN) and side-mode suppression ratio (SMSR). Consistent RIN performance < -150 dB/Hz and SMSR better than 45 dB are demonstrated for all channels and wavelengths in Fig. 2(c). The transmitters operate with low RIN noise and high SMSR across the full operating temperature and bias current range. The tight process control leads to low variability in transmitter performance in laser wavelength, bias current of laser, SMSR, RIN and transmitter output power across devices sampled across the entire 300 mm wafer.

In [4], we described the optimization of our silicon photonics TWMZM for 400G DR4 and FR4. As 800G PAM4 has more stringent power consumption requirements, additional improvements to our TWMZM were necessary. In the DR8 transmitter, we employ differentially driven carrier-depletion TWMZMs as shown in Fig. 3(a). Relative to our 400G design [3], an improved pn junction was designed with the further trade-off optimization between the phase efficiency and the bandwidth, which maintained optical modulation amplitude (OMA) and transmitter and dispersion eye closure quaternary (TDECQ), while creating a path towards reducing the driver swing and thus the power consumption.

A second step of optimization explored trade-offs associated with modulation depth and bandwidth from the choice

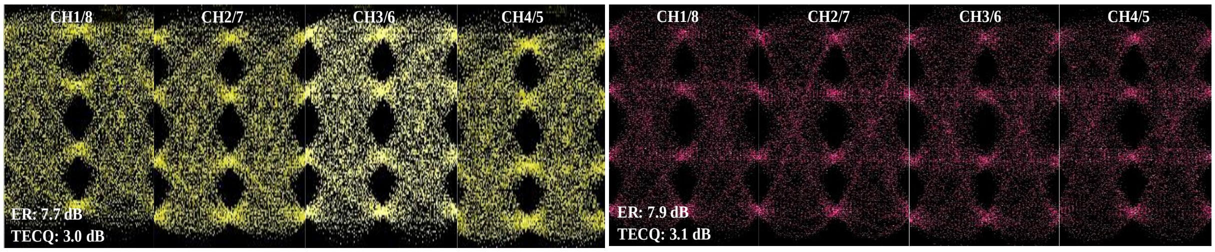


Design	ER [dB]	TECQ [dB]	Rel. OMA – TECQ [dB]
L1, T1	6.7	2.8	0
L2, T1	7.7	2.9	+0.3
L1, T2	6.0	2.7	-0.3
L2, T2	6.8	2.8	-0.02

(a) (b) (c)

Figure 3: (a) Schematic of the TWMZM design. Simulated (b) differential EO S21, and (c) key Tx metrics of optimization subset.

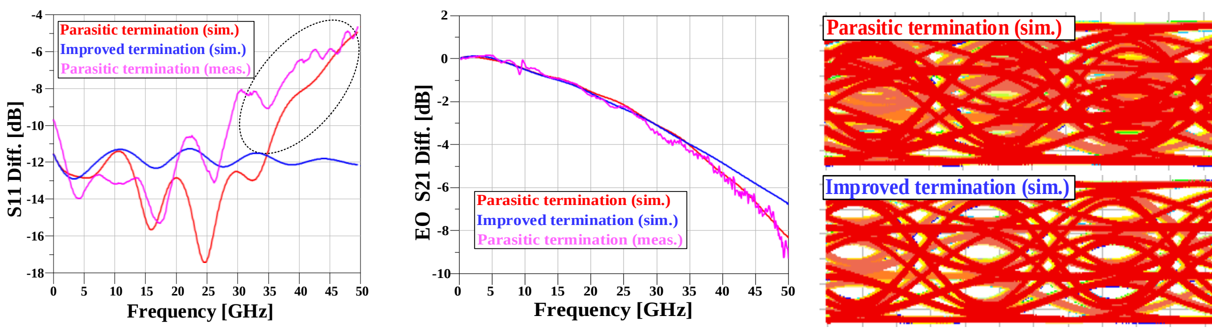
of the phase shifter length (L) and the termination (T). EO S21 from four select combinations are shown in Fig. 3(b), and Fig. 3(c) summarizes the simulated room temperature (RT) key Tx metrics from the TWMZM in a transmitter optical subassembly (TOSA). The simulations match RT measurements for all channels. Fig. 4(a) and 4(b) show the measured eye diagrams at RT and 80°C, respectively for four representative channels considering the symmetrical channel configuration in DR8 Tx. The average extinction ratio (ER) and transmitter eye closure quaternary (TECQ) are also listed. For this test, the TWMZM was driven by a 53.125 Gbaud PAM4 electrical signal from a 50 Ω arbitrary waveform generator. Further trade-offs in extinction ratio and power consumption can be made by reducing driver swing, while still meeting product specs.



(a) (b)

Figure 4: Measured 53 Gbaud four representative channels of TOSA eye diagrams after the TDECQ filter at (a) RT, and (b) 80°C. No equalization at Tx.

Although the current design meets specifications, a further refinement will be the elimination of the swift increase in RF reflection (S11) at higher frequencies, as visible in Fig. 5(a). The source of this is a parasitic inductance in the current TWMZM termination network. An improved termination is expected to yield the smooth blue curve of Fig. 5(a). The corresponding EO S21 responses and eye diagrams are shown in Fig. 5(b) and 5(c), respectively. Though there is no increase in -3 dB BW, simulations predict clearer eye diagrams and a reduction in TDECQ in a TOSA-like test bench. This will further increase margins in the strict requirements of 800G 2×FR4 and DR8 products.



(a) (b) (c)

Figure 5: Measurement and simulation of (a) differential S11, and (b) differential EO S21. (c) Simulated eye diagrams pre-TDECQ filter.

3. Conclusion

An industry-first 8×100Gbps PAM4 2×FR4 and DR8 fully integrated silicon photonics transmitter is demonstrated, highlighting the bandwidth scalability of Silicon Photonics for 800G data center applications. This successful demonstration of 2×FR4 and DR8 transmitter with 100G traveling wave modulators with on-chip high power DFB lasers further expands the capability of the heterogeneous laser integration platform and paves the way for future 1.6 Tbps and 3.2 Tbps high-density optical connectivity applications.

4. Acknowledgements

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5. References

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