400Gbps Fully Integrated DR4 Silicon Photonics Transmitter for Data Center Applications

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Abstract: A 400Gbps PAM-4 fully integrated DR4 silicon photonics transmitter with four heterogeneously integrated DFB lasers has been demonstrated for data center applications over a temperature range of 0~70°C and a reach of up to 2km

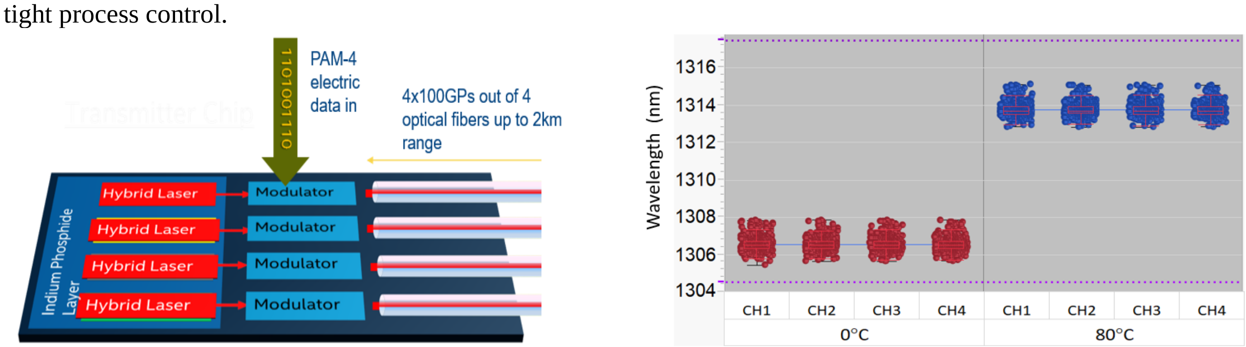
OCIS codes: (130.0130) (130.3120)

1. Introduction

With the continuously increasing bandwidth demand, data center connections are moving from 100G to 400G, and silicon photonics has been a key enabling technology to meet the requirements of high speed connectivity between servers and switches within data centers. In particular, silicon photonics with fully integrated optics (including lasers) has been successfully deployed in 100G PSM4 and CWDM4 QSFP products for data center applications by leveraging the advantage of silicon manufacturing and wafer level test, resulting in scalability and cost efficiency [1][2]. In this paper, by scaling up from our 100G silicon photonic platform to 400G, we successfully demonstrate the industry's first fully integrated 4 x 100 GB/s DR4 silicon photonics transmitters for 400G applications over a temperature range from 0°C to 70°C and a reach of up to 2km with excellent reliability.

2. Experiments and results

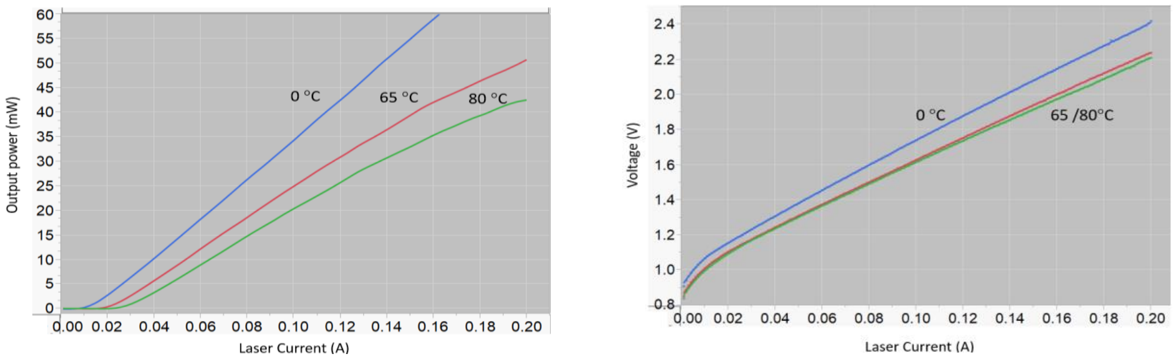
The 4 x 100Gbps DR4 silicon photonics transmitter with heterogeneously integrated distributed feedback (DFB) lasers (1311nm nominal wavelength) and 100Gbps traveling wave Mach-Zehnder Interferometer modulator (MZM) are depicted in Figure 1(a). These optical components and other photonic passive devices are fabricated using Intel's 300mm heterogeneous integration process as described in previous work [1]. Figure 1 (b) shows the accurate targeting of four channels of wavelength across the whole data center application temperature range of 0°C to 80°C with tight distribution (a standard deviation of 0.3nm) on a 300mm wafer. This is enabled by robust laser design and tight process control.



(a) (b)

Figure 1: (a) Illustration of DR4 transmitter with 4x100Gbps data paths, (b) DR4 transmitter center wavelength with upper spec limit (USL) and low spec limit (LSL) (dotted lines) from 0°C to 80°C chip temperature across 300mm wafer.

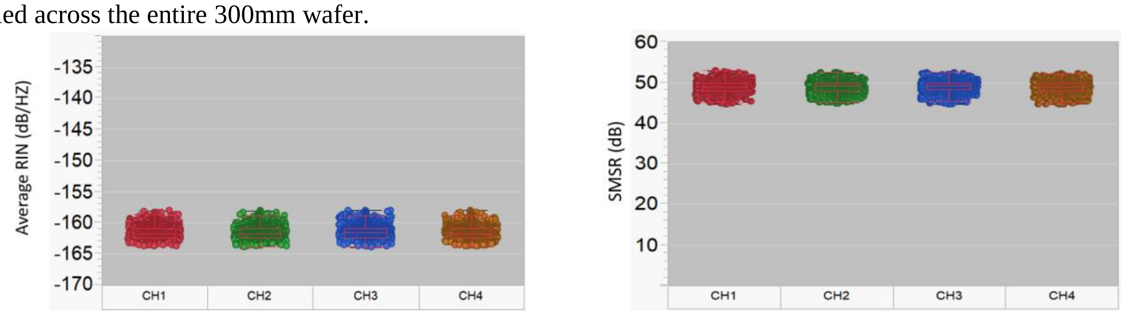
Figure 2 (a) illustrates a typical Light-Current characteristics for the III/V-Si Hybrid DFB laser. Laser output power exceeds 40mW at 80C° with no sign of thermal rollover. Figure 2 (b) shows that the voltage for these operating powers can meet the requirement at all temperatures for data center applications. The power performance of these hybrid lasers, where light is already coupled to the silicon waveguide, compares favorably to discrete lasers fabricated on native InP substrate. The accurate wavelength control combined with superior laser power performance up to 80°C chip temperature enables the uncooled operation of DR4 transmitters across the DR4 module temperature range of 0°C to 70°C.



(a) (b)

Figure 2: (a) Light (coupled in the Silicon Waveguide) versus Current characteristics of III/V-Si DFB laser from 0°C to 80°C,(b) IV curve for laser at 0°C, 65°C and 80°C

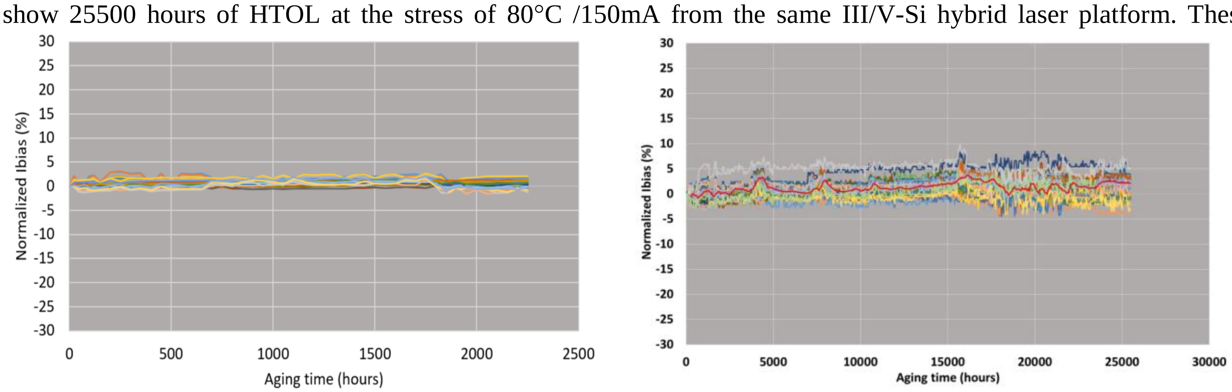
The stability and spectral integrity of this DR4 transmitter are characterized at 0°C which is generally the worst case operating condition for the key performance parameters such as relative intensity noise (RIN) and side-mode suppression ratio (SMSR). Consistent RIN performance < -155dB /Hz and SMSR better than 45dB are demonstrated in Figure 3 (a) and (b). 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 and voltage of laser, SMSR, RIN and transmitter output power across devices sampled across the entire 300mm wafer.



(a) (b)

Figure 3 DR4 transmitter (a) average RIN distribution and (b) SMSR distribution at 0°C across 300mm wafer

Reliability is also an important challenge to meet for DR4 applications, as the laser output power required is more than double that of 100G applications. Figure 4 (a) 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 DR4 laser after being stressed at a temperature of 80°C with a stress current of 200mA for 2250 hours up to date. In figure 4 (b), we show 25500 hours of HTOL at the stress of 80°C /150mA from the same III/V-Si hybrid laser platform. These

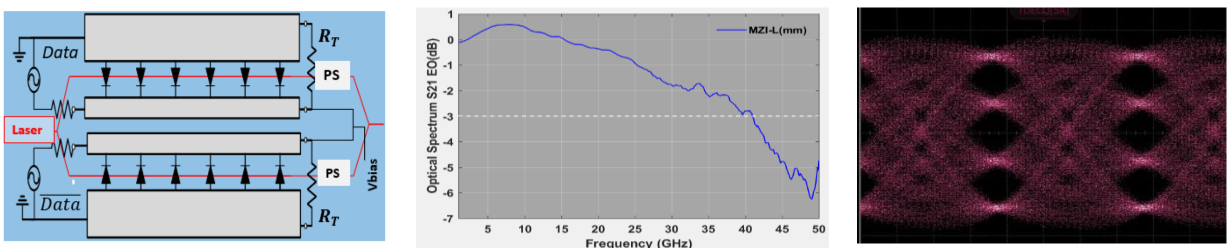


(a) (b)

Figure 4: Relative drift of bias current required for DR4 laser operating power for III/V-Si lasers stressed (a) at a stress condition of 80°C/200mA for 2250 hours, and (b) 80°C /150mA for 25500 hours

results, coupled with other accelerated aging test results ran at 150°C and 150mA, show that the lasers can meet the reliability and life time requirements for 400G applications.

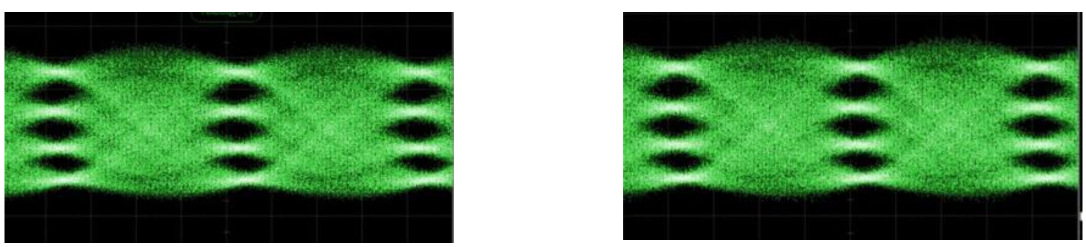
The traveling wave MZM integrated in the DR4 transmitter is schematically illustrated in Figure 5 (a) with only one channel depicted for simplicity. It is composed of a pair of PN junction based phase shifters working in depletion mode. With the optimized designs of PN junction doping, transmission line, phase-shifter (PS) length and bias condition, the measured 3-dB EO BW of the MZM is 40GHz at the operation voltage bias with matched impedance of terminator as shown in Figure 5 (b). The high speed performance of this modulator is further demonstrated by the eye performance of the transmitter optical subassembly (TOSA) built from this fully integrated DR4 transmitter. The TOSA is driven by an Arbitrary Waveform Generator with a 53.125 GBaud/s electrical PAM4 signal, and the measured ER and TDECQ are 5.7 dB and 2.6 dB respectively without the equalization applied as shown by the PAM-4 eye performance in Figure 5 (c)



(a) (b) (c)

Figure 5: (a) schematic of DR4 TW-MZM, (b) 3-dB EO BW of TW-MZM under the optimized length and bias condition at room temperature, (C) TOSA PAM-4 eye performance at room temperature

The back-to-back PAM-4 eye performance of a DR4 module built from the TOSA described above is demonstrated in Figure 6 for a representative channel at module case temperatures of 0°C and 70°C. Under the 53.125 GBaud/s electrical PAM4 signal, and optimized operating conditions and equalization, the measured ER and TDECQ are 5.5 dB and 1.6 dB respectively at 0°C, and 4.9 dB and 1.8 dB respectively at 70°C. This demonstrated DR4 module PAM-4 eye performance indicates that the DR4 module with fully integrated DR4 transmitter can well meet the requirements for 400G data center applications.



(a) (b)

Figure 6: DR4 Module PAM-4 eye performance (a) at 0C, and (b) 70°C (module case temperature) at 53.125 GBaud/s under optimized operating conditions and equalization

3. Conclusion

An industry-first 4×100Gbps DR4 fully integrated silicon photonics transmitter is demonstrated, providing bandwidth scalability of our commercial Silicon Photonics technology for 400G data center applications. This successful demonstration of a DR4 transmitter with 100Gbps traveling wave modulators including high power and reliable DFB lasers further expands the capability of the heterogeneous laser integration platform, and positions it well to support future types of high-density optical connectivity applications.

4. References

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