Ultra Compact Athermal 400G-FR4 Silicon Photonics Receiver with Polarization Diversity

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Abstract: We have successfully demonstrated an ultra-compact WDM 400G-FR4 ROSA module integrated with silicon photonics circuits operating at 53.125Gbaud PAM4 signal with a sensitivity of -6.0dBm optical modulation amplitude at KP4 Pre-FEC-BER=2.4e-4.

1. Introduction

Optical transmission speeds of 100G have been introduced in data centers as the work horse for interconnecting datacenter switches, servers, and router racks. Small-form factor pluggable fiber-optic transceiver (FOT) modules such as CFP4 and QSFP28 are used as core interconnect devices and consumed in very high volume within hyperscale data centers and for high-performance computing applications. The 400G-FR4 optical communication standard is being promoted by 100G Lambda MSA [1] toward the realization of higher capacity and higher speed communication, and the development of new FOT form factors such as QSFP-DD and OSFP modules. The need for high-bandwidth density, high-temperature operation, and ultra-compact packaging of integrated silicon photonics transceivers for datacenter communication systems is increasing due to the demands imposed by big data, 5G and IoT (Internet of Things). Furthermore, full integration of passive optical components such as wavelength mux and a demux filters as part of SiPh transmitter and receiver chips reduces the overall cost of modules by simplifying the component count, build process, and test time.

Increasing the energy efficiency per photon, and lowering the cost per bit, while increasing the interconnection capacity necessitates the reduction of discrete electronic ICs, photonic ICs, integration of optical components, WDMs, lasers and reducing photonic component dimensions. Silicon photonics can easily integrate key transmitter and receiver components onto a single chip, such as edge couplers, polarization beam splitter rotators, variable optical attenuators (VOA), athermal WDM filters, and Ge photodetectors (PDs) that are operated with polarization diversity. In this work, we have successfully demonstrated 400G (100-Gbps CWDM4: 1271nm, 1291nm, 1311nm and 1331nm) FR4 receiver optical sub-assembly (ROSA) by full optical integration on a silicon photonic chip for 53.125-Gbaud PAM-4 signal (Fig. 1(a)).

(a)

(b)

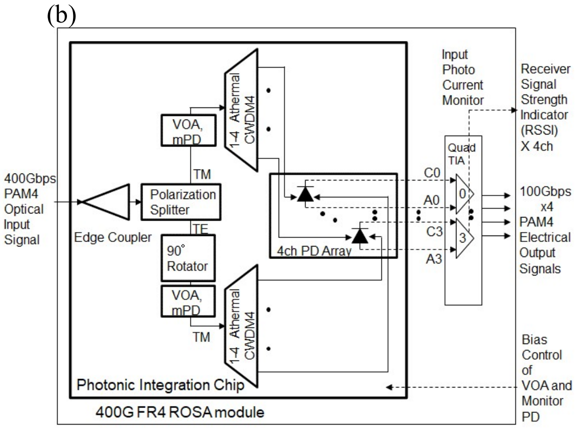

Fig. 1 (a) The appearance of 400-Gbps FR4 ROSA (b) The functional block diagram for 400-Gbps FR4 ROSA

2. Design and Fabrication of ROSA

The 400-Gbps FR4 ROSA consists of the silicon photonic integrated circuit, a transimpedance amplifier (TIA), a hermetically sealed package, and a flexible printed circuit (FPC) board with Z0=100Ω differential impedance lines as shown in Fig 1(a). Figure 1(b) shows the block diagram for the 400-Gbps FR4 ROSA. This ROSA greatly simplifies assembly and reduces manufacturing costs by using a single silicon photonic and TIA chip rather than discrete, DEMUX, lenses, mirrors, and photodetectors. A photograph of the 400G FR4 ROSA package inside the assembly is shown in Fig.2. In the package, the PIC and the TIA are electrically interfaced by wire-bonds. 4 channels of 53.125-Gbaud PAM4 signals are routed by 4 Z0 = 100Ω differential impedance lines on the FPC. As a results, we have realized a compact ROSA with 230 mm3 (6.7mm x 6.0mm x 5.7mm) package volume, excluding the optical receptacle. This compact footprint is sufficient for future integration inside QSFP-DD transceiver form factors.

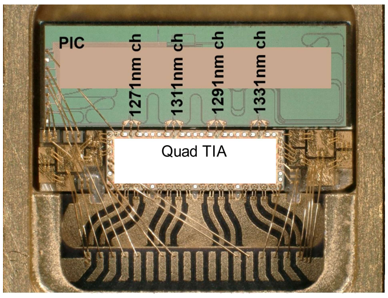

Fig.2 Photograph view of ROSA package inside including PIC and Quad TIA

(a) (b)

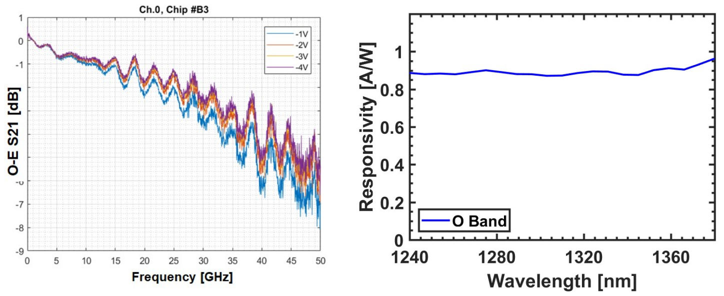

Fig.3 Optical Characteristics of the Ge photodiode in PIC (a) Frequency response (b) Responsivity on O-band

3. Design and Fabrication of ROSA

The O-band photodetectors use a vertical p-i-n junction within the germanium layer for photocurrent generation. The frequency response and responsivity of Ge PD are shown in Fig. 3(a) and 3(b), respectively. The 3-dB bandwidth and responsivity are 34 GHz and over 0.8A/W respectively, making it suitable for 53.125-Gbaud PAM-4 transceiver applications.

(a) (b) (c)

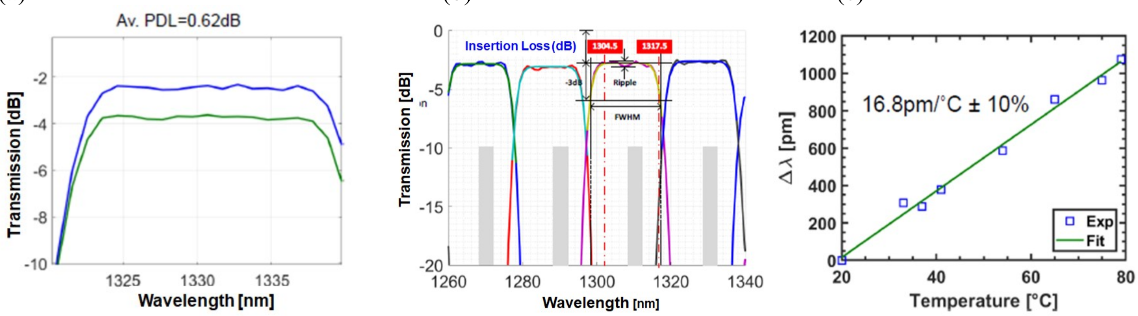

Fig.4 Polarization and Temperature dependence of PIC (a) Polarization independent loss of optical transmission loss (b) The optical spectrum od DEMUX in the wavelength range of 4ch CWDM (c) Wavelength shift of CWDM passband as a function of temperature

Next, to realize practical operation, a polarization splitter and TM to TE converter are used to achieve polarization diversity [2]. As can be seen in Fig. 4(a), the polarization dependent loss (PDL) was found to be less than 0.7dB. Furthermore, to enable on-chip coarse wavelength division demultiplexing of the 4 channels, we have developed passive athermal DEMUX CWDM4 filters with all-passive PIC components. A typical transmission spectrum of the CWDM4 filter is displayed in Fig. 4(b), providing a flat-top and low insertion loss while maintaining a <-25dB channel crosstalk across a 14 nm channel passband frequency, exceeding the FR4 standard [2]. We also measured the temperature dependency for the shift of wavelength (Δλ) in the DEMUX as shown in Fig. 4(c). The 16.8pm/°C slope enables the DEMUX to be used across a wide temperature range from 25°C to 80°C.

Finally, low-loss optical coupling to the ROSA has been realized by an edge coupler with a 7 um mode field diameter at the PIC facet, and an aspherical lens in the receptacle, which focuses the input fiber mode to a 6 um diameter. As a result, the coupling loss of whole ROSA optical assembly module between the PIC and the receptacle could be realized with 1.5dB. The total insertion loss of PIC was measured to be 2.5dB.

4. Experimental Results of Signal Transmission

The bandwidth of the ROSA is shown in Fig.5(a) and is normalized at the low frequency point. The variation between channels was found to be very small. The 3dB bandwidth is 34 GHz. This bandwidth is sufficient to operate 53-Gbaud PAM-4. The measured waveform eye diagram of the ROSA is shown in Fig.5(b) for 53.125-Gbaud PRBS13Q signal pattern with Gray code using 11-tap Feed Forward Equalization (FFE). The eye diagram remained unchanged for measurements made for case temperatures of 26°C and 80°C.

(a) (b)

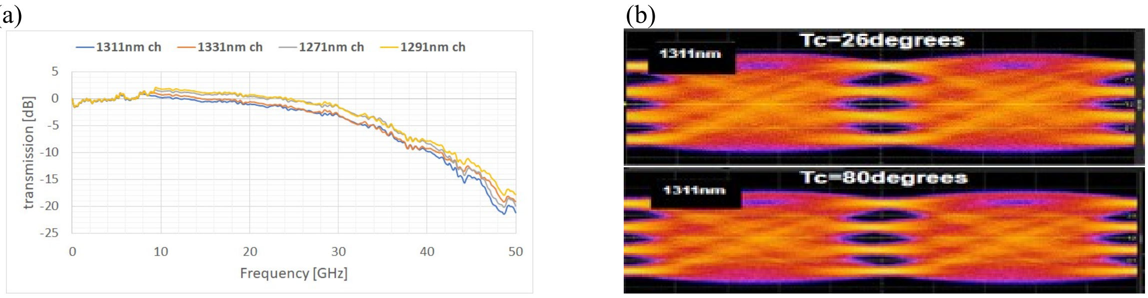

Fig.5 (a) Bandwidth of ROSA (b) Output waveform eye diagrams of ROSA at the case temperature (Tc) of 26°C and 80°C for 53.125 Gbaud PAM4 signals

The bit error rate for all output channels is shown in Fig.6(a) using 53.125-Gbaud PRBS13Q signal pattern with gray code. The minimum sensitivity for optical modulation amplitude (OMA) was -6.0dBm at FEC limit with bit error rate of 2.4e-4. For these measurements, an Anritsu MP1900A was used as the PAM4 pulse pattern generator. The PAM4 bit error rate and the eye diagram were measured with a Keysight real time scope. Fig. 6(b) shows negligible temperature dependency of the bit error rate for operating temperatures of Tc=26°C, 60°C and 80°C.

(a) (b)

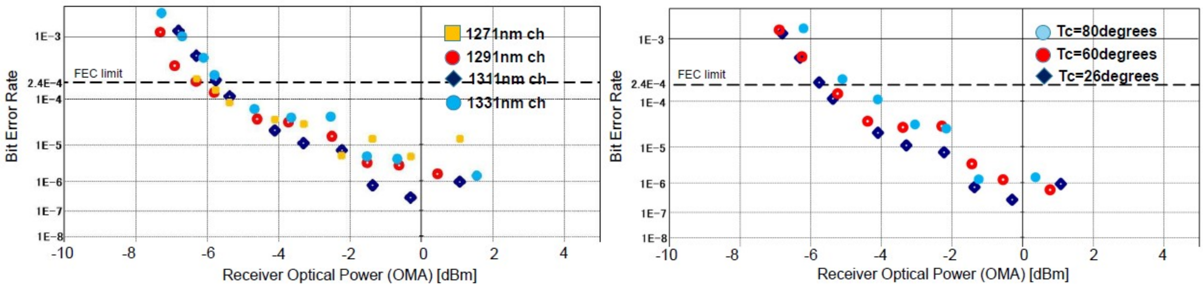

Fig.6 (a) BER for ROSA of all output channels (b) Temperature dependency for BER at 26°C, 60°C and 80°C

5. Conclusion

We have designed and developed a 400-Gbps FR4 ROSA featuring a compact silicon photonic integrated chip. Its performance was verified by eye diagram and BER measurements. The silicon PIC transceiver's tolerance to high and varying case temperatures is also verified. This ROSA would be compatible with transceiver modules such as 400G QSFP-DD, which is compliant with IEEE 802.3bs and 100G Lambda MSA standards. It's athermal performance would also allow it to operate in uncooled data center environments [3].

6. Acknowledgement

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7. References

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