Real-Time 100 Gb/s NRZ-OOK Transmission with a Silicon Photonics GeSi Electro-Absorption Modulator

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Abstract: We demonstrate single-wavelength, serial and real-time 100 Gb/s NRZ-OOK transmission over 500 m SSMF with a GeSi EAM implemented on a silicon photonics platform. The device was driven with 2 Vpp without 50 Ω termination, allowing a low-complexity solution for 400 GbE short-reach optical interconnects.

1. Introduction

The increasing growth of internet traffic pushes the requirements on the intra-datacenter high-speed optical interconnects. This has led to the evolution from 100 Gb/s Ethernet to 400 Gb/s Ethernet, for which the implementation options are currently under discussion [1]. A four lane 100 Gb/s scheme could be a relatively simple approach to achieve this goal allowing lower lane counts and as such, a higher spatial efficiency. Previously, 100 Gb/s single-lane transmissions have been realized using PAM-4, discrete multi-tone (DMT), and electrical duobinary (EDB), but most of these demonstrations relied on heavy off-line digital signal processing (DSP) [2-5]. 112 Gb/s PAM-4 modulation of a discrete Mach-Zehnder modulator at 8.6W power consumption was demonstrated in [6]. In [7] EDB was used at 100 Gb/s in combination with a travelling-wave electro-absorption modulator with integrated DFB-laser in an InP photonic integrated circuit and in [8] 100 Gb/s non-real-time OOK transmission was achieved through a silicon-organic-hybrid modulator. Although the required drive voltages in [8] and [10] are comparable to our experiment, the transmission line structure of the modulator electrode necessitates a power-consuming 50 Ω termination. Here we present 100 Gb/s NRZ-OOK transmission of a compact, lumped Germanium-Silicon EAM without 50 Ω termination integrated on a silicon photonics platform, in combination with an in-house designed transmitter (TX) and receiver (RX) chipset in a SiGe BiCMOS technology. This is the first real-time 100 Gb/s NRZ-OOK transmission with a silicon-based modulator without any DSP.

2. Experiment Setup

The EAM was fabricated in imec's 200 mm silicon photonics platform and consists of an 80 μm long and 600 nm wide germanium waveguide with embedded lateral p-i-n junction, connected to silicon waveguides. The operation is based on the Franz-Keldish effect, which shifts the band edge of Ge by applying an electrical field [9]. Light is coupled in and out of the waveguide structure through fiber-to-chip grating couplers (IL = ~6 dB/coupler). Electrical RF probes, without any termination, are used to apply the high-speed signal and the bias voltage to the EAM. Figure 1 shows the schematic of the setup for the transmission experiments. Four individual 2^7-1 long pseudo-random bitstreams (PRBS) are generated at 25 Gb/s on a XilinX FPGA-board and multiplexed with the required delays to form again a 2^7-1 long PRBS at 100 Gb/s. An analog six-tap feedforward equalizer (FFE) on the transmitter IC is used to compensate frequency roll-off and non-idealities of the following components and the link. A RF amplifier with internal bias-T delivers a swing of ~2 Vpp to the modulator.

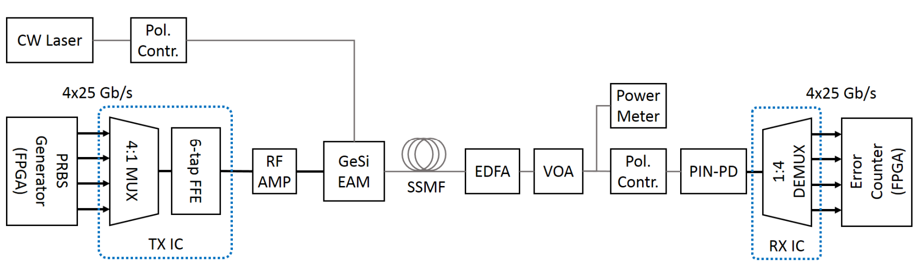

Figure 1. Experimental setup

978-1-5090-5016-1/17/$31.00 ©2017 IEEE

The EAM was biased at -1.85V. The waveguide-coupled laser power was 7.5 dBm at a wavelength of 1601.5nm. With these settings we estimated a dynamic extinction ratio of ~6.5 dB and an insertion loss of ~7 dB for the modulator. No temperature control was used during the experiments. As no high-speed transimpedance amplifier with sufficient bandwidth was available, we had to increase the signal power with an EDFA before coupling to a commercial PIN-photodiode (BW=50GHz). Finally, the receiver IC deserializes the 100Gb/s signal into 4x 25Gb/s streams and provides these to the FPGA for real-time error detection without the need for complex DSP. The TX and RX ICs were designed in-house in a 0.13µm BiCMOS technology [7, 10]. The TX IC occupies ~ 1.5 mm x 4.5 mm and consumes <1 W. The RX IC occupies ~ 2 mm x 2.5 mm and uses less than 1.2 W.

3. Results and Discussion

Optical performance of the link was verified using the setup shown in Fig. 1. At a rate of 100 Gb/s NRZ almost all the components in the E/O/E-link (65 GHz RF Amp, 50 GHz PIN-PD, cables and connectors, fiber dispersion,...) influence the overall response in the frequency range of interest. The frequency response of the optical link (from RF Amp to PIN-PD) for different lengths of fiber can be seen in Fig. 2 (b). We clearly see that standard single mode fiber (SSMF) operating in L-band (1601.5nm) severely degrades the flatness of the frequency response at longer fiber spans. Nevertheless, we still manage to obtain bit-error ratios (BER) comfortably under the hard-decision forward error coding limit of 3.8×10^{-3} (HD-FEC with 7% overhead) over 500 m of SSMF as shown in Fig. 2 (a). Investigating the eye diagrams in Fig. 2 (c) and (d) for B2B and 500m transmission captured directly after the PIN-PD with a 70 GHz sampling scope, we believe that the BW of the RX IC (41 GHz) is the most significant contributor to the total BW, limiting the overall link performance. Tests with a new and faster version of the RX IC are planned.

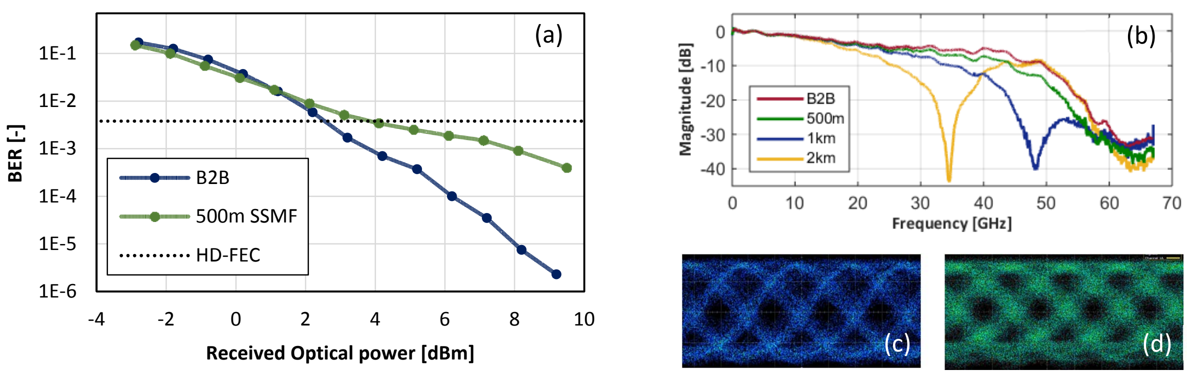

Figure 2. (a) Real-time BER curves for B2B and 500 m fiber transmission; (b) Frequency response of the optical link (from RF Amp to PIN-PD) for different lengths of SSMF at 1601.5nm; Captured 100 Gb/s NRZ eyes from photodiode (c) back-to-back and (d) after 500m SSMF fiber.

4. Conclusion

We have demonstrated a GeSi EAM fabricated in a 200 mm silicon photonics platform that is capable of transmitting 100 Gb/s NRZ in combination with an in-house designed SiGe BiCMOS transmitter and receiver chipset. Successful transmission over 500 m of SSMF was achieved and verified in real-time without any offline DSP, paving the way for a compact, low-complexity silicon photonic transceivers for 400 GbE short-reach optical interconnects.

5. Acknowledgement

This work was supported by the imec IAP on Optical I/O for the Ge EAM, the UGent IOF for the Tx/Rx ICs, the H2020 TERABOARD project, the UGent BOF and the FWO.

6. References

[1] "IEEE P802.3bs 400 Gigabit Ethernet Task Force." [Online]. Available: http://www.ieee802.org/3/bs/
[2] C. Yang et al, IEEE Photonics Journal, vol. 8, no. 3, 2016.
[3] K. Zhong et al, Optics Express, vol. 23, no. 2, pp. 1176–1189, 2015.
[4] D. Sadot et al, in Optical Networking and Communication Conf., Los Angeles, 2015
[5] J. Lee et al, in Optical Networking and Communication Conf., San Francisco, 2014.
[6] J. Lee et al, in ECOC , ID:0604, Valencia, 2015.
[7] M. Verplaetse et al., Journ. of Lightw. Techn., (2017), to be published
[8] W. Hartmann et al., in ECOC, ID:1078, Valencia (2015)
[9] S. A. Srinivasan et al, OFC, Anaheim, CA, 2016, pp. 1-3.
[10] T. De Keulenaer et al., Electronics Letters, vol. 51, no. 4, pp. 343–345, 2015