170 Gbaud On-Off-Keying SiP Ring Resonator Modulator-based Link for Short-Reach Applications

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***Abstract*— We demonstrate a record 170 Gbaud on-off keying C-band silicon photonics ring resonator modulator-based transmitter with performance below the 6.7% overhead HD-FEC threshold after optical back-to-back and transmission over 100 m silicon photonics, ring resonator modulators, on-off keying, short-reach communication, intensity modulation direct detection single mode fiber.**

Keywords*— *silicon photonics, ring resonator modulators, on-off keying, short-reach communication, intensity modulation direct detection

I. Introduction

Silicon photonics (SiP) is a key enabling technology for future 800 Gbps and 1.6 Tbps solutions in scalable and energy efficiency way. Recent advances [1-8] in SiP enable dense integration, high yield and low energy consumption for optical interconnects. Monolithic integration of SiP and complementary metal-oxide semiconductor (CMOS) eliminates need of additional packaging and integration allowing to introduce compact arrayed waveguide grating routers [1] or extremely efficient wavelength division multiplexing filters [2]. All silicon avalanche photodiode [3] has demonstrated 0.73 A/W more than 38 GHz RF bandwidth in O-band operation. High-bandwidth SiP slow light modulator [4] and wide free spectral range SiP ring resonator modulator (RRM) [5] have been demonstrated. On-off keying (OOK) at highest symbol rate should be considered thanks to high energy efficiency and simple driving electronics. SiP RRM was used to demonstrate 160 Gbaud OOK [6]. SiP RRM with integrated laser demonstrated 128 Gbaud OOK/PAM4 [7]. Multichannel integration advantages of SiP RRM have been shown by implementing 4 x 224 Gbps [8] in O-band.

In this paper, we report on SiP RRM-based transmitter to achieve record performance below 6.7% overhead (OH) hard-decision forward error correction (HD-FEC) threshold of 4.5×10^{-3}. We demonstrate up to 170 Gbaud on-off keying (OOK) transmission for ob2b and transmission over 100 meters of single mode fiber (SMF).

II. Experimental Setup

Fig. 1 (a) shows the experimental setup for testing SiP modulator. The signal bit sequence for OOK is generated offline in MATLAB from a random binary sequence of >1 million bit-length obtained using the Mersenne Twister generator with a shuffled seed number. The obtained bit sequence is firstly digitally up-sampled to 4 samples per symbol, pulse-shaped with root-raised-cosine (RRC) filter with roll-off factor of 0.5, and down-sampled to 256 GSa/s to match the sampling rate of the arbitrary waveform generator (AWG, Keysight M8199B). The output voltage swing of the AWG is set to be 2.7 Vpp. RRM modulators is reverse biased using 110 GHz bias-tee at 1.5 V after optimization. Signal and bias are applied to modulators using 110 GHz RF probes. The output power of the tunable laser is set to 15.5 dBm and coupled into the modulators using grating couplers. Insertion loss of RRM at different bias voltages (see Fig. 1 (b)), as well as relative responses at different detuning levels are (see Fig.1 (c)), are measured using Keysight Integrated Photonics Test Setup [13] at 1.5 V reverse bias. Modulator extinction ratio at different detuning values is shown in Fig.2 (c).

As one can see RRM modulator shows smooth roll-off in the frequency transfer function makes the usable modulator bandwidth beyond 67 GHz. Resonance frequency around 1536 nm is chosen after optimization as it has lowest insertion loss

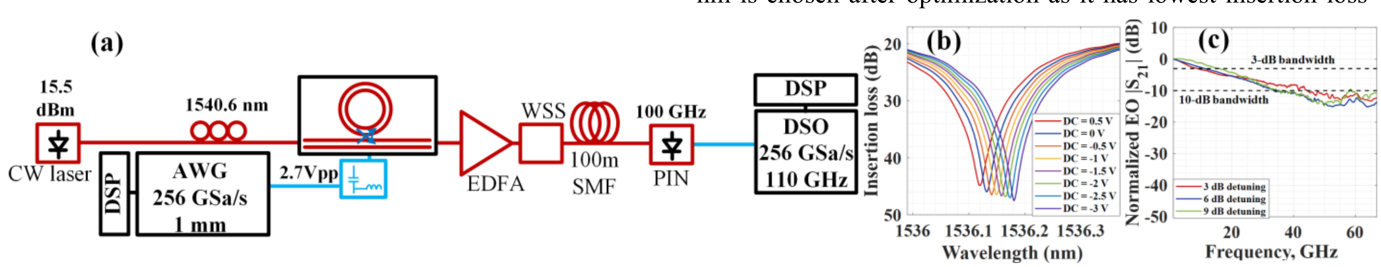

Fig. 1. (a) Experimental setup for ring resonator modulator testing. Measured (b) RRM insertion loss at different biasing voltages and (c) EO response for 3-, 6-, and 9-dB detuning points.

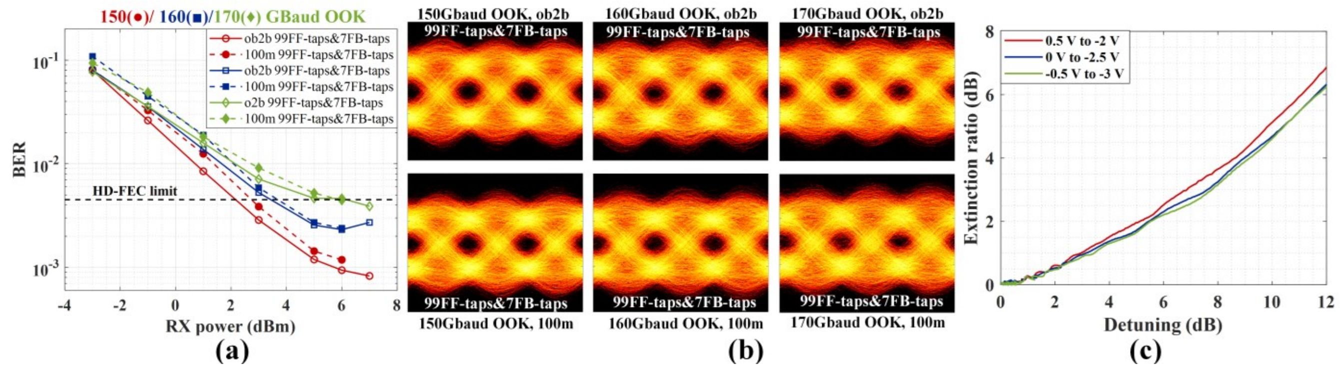

Fig. 2. (a) BER results as a function of RX power and (b) eye-diagrams for 170 Gbaud, 160 Gbaud and 150 Gbaud OOK for ob2b and after transmission over 100 m SMF with C-band SiP RRM. (c) RRM extinction ratio as function of detuning.

enabling room for higher detuning of RRM. To avoid RRM instability due to self-heating, the heater current is set to 6.5 mA effectively shifting the resonance to 1540.7 nm. After optimization tunable laser wavelength is set to 1540.612 nm, corresponding to 9 dB detuning. It allows RRM to achieve 4.1 dB extinction ratio at cost of higher modulator loss.

After optical modulation the signal is transmitted over 100 m of SMF. An Erbium-doped fiber amplifier (EDFA) with an output power of 13 dBm is used to overcome coupling losses. Wavelength selective switch (WSS) is used to filter out the amplified spontaneous emission noise, resulting in up to 7 dBm optical power on 100-GHz PIN photodiode (PD). The signal from PD is delivered to a real-time digital storage oscilloscope (DSO, 256 GSa/s, Keysight UXR1104A). Finally, the signal is processed with a matched filter, a timing recovery and down-sampling process based on maximum variance, a symbol-spaced decision-feedback equalizer (DFE) with different feedforward (FF)-taps and feedback (FB)-taps, and the BER performance is counted after the offline demodulation.

III. Results and Discusions

We evaluate the performance of RRM modulator with on-off keying modulation format at a 6.7 % OH HD-FEC threshold of 4.5×10^{-3} for optical back-to-back (ob2b) and after transmission over 100 m of SMF. In Fig. 2, we show BER as a function of received optical power for SiP RRM transmitter and the selected eye diagrams for ob2b and after transmission over 100 m of SMF, captured at the highest received optical power (RXpower) with the same DFE configuration as for the bit error rate (BER) curves.

As one can see from Fig. 2 (a), we evaluate performance of 150 Gbaud, 160 Gbaud and 170 Gbaud OOK signals for ob2b and after transmission over 100 m of SMF using DFE with 99 FF-taps and 7 FB-taps. We observe power penalty after transmission over 100 m of SMF due to high chromatic dispersion (CD) coefficient in C-band. Fig. 2 (b) shows eye-diagrams of 150 Gbaud, 160 Gbaud and 170 Gbaud OOK signals at +7 dBm for ob2b and +6 dBm after transmission over 100 m SMF. As one can observe from Fig. 2 (b), all data rates show open eye diagrams. Slight reduction of eye-opening is observed after transmission over 100 m SMF due to chromatic dispersion impact in C-band.

IV. Conclusions

We demonstrate C-band SiP RRM-based transmitter to achieve performance below 6.7% OH HD-FEC threshold of 4.5×10^{-3}. We demonstrate record 170 Gbaud OOK SiP RRM for ob2b and after transmission over 100 m SMF. We show open eye diagrams for both transmission scenarios. This paves the way for compact high symbol rate transceivers based on silicon photonics RRM modulators.

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