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Singe 120 Gbit/s Operation of Silicon-Polymer Hybrid Modulator

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Abstract

We demonstrate polymer based efficient optoelectronics, in particular electro-optic modulator, for over 100 Gbaud capable modulation. The fabricated modulator consists of a silicon and polymer hybrid (SPH) layer-by-layer, which enables 120 Gbit/s on-off-keying (OOK) and short reach optical fiber transmissions with no bit-error failures under the forward error correction threshold.

1. Introduction

The high-speed signaling of the electro-optic (EO)transmitters is one of the promising building functions inside the device for fiber-optic-based interconnects. The exponentially growing bandwidth requirement in the next-generation optical communication networks drives the development of optical transmitters to higher achievable data rates. As the optical interconnect bandwidth keeps growing, next generation transmission links will need to be upgraded to 200 GbE and 400 GbE, and further upcoming operation for 0.8 Tb/s or 1.6 Tb/s links.

So far, several efficient single 100 Gbit/s EO modulators have been demonstrated and fabricated using several photonic platforms, such as silicon [1], indium phosphide [2], organic polymer [3], lithium niobate [4], and plasmonics [5], showing distinct advantages including the potential of the integration with CMOS electronics, low drive voltages, ultra-high bandwidths, and small footprint. Among the different types of materials used in the modulator, the EO organic or polymer offers intrinsic advantages such as a large electro-optic efficiency (r_{33}>100 pm/V), low dielectric constant and loss, and excellent compatibility with other materials and devices. Previously, the EO polymer modulators have shown outstanding performance in terms of high data rate, low power consumption, and excellent compatibility with other materials and silicon-on-insulator waveguides. The low fabrication cost and high yield of the polymer devices are another advantage, thus providing a cost-effective solution to high-volume production of high-speed optical transmitters.

Given the above figure-of-merit, the EO polymer modulator offers the cost effective technology for short reach interconnect, i.e. intra datacenter (DC) networking. Intra-DC interconnects have shorter reach compared to the traditional long-distance telecommunications and consist of a large number of connections. Thus, their cost is largely dominated by the optic devices, which have stringent requirements on power consumption, density, and cost due to their sheer volume. Further, scaling the bandwidth efficiency from 400 Gbit/s per fiber to beyond 1 Tbit/s per fiber will be a challenging. Fundamentally, there are three directions to scale interconnect bandwidth: a) enhanced symbol rate per lane; b) increased number of parallel lanes; and c) more bits encoded per symbol. Among these three directions, symbol rate is the fastest method to scale the bandwidth. Therefore, it will be a challenge to further double the symbol rate of modulation from 50 Gbaud to 100 Gbaud and thus require >70 GHz optical and electrical component bandwidth. The EO polymer modulator with the traveling-wave-electrode has the large potential to realize such high baud rate operation. Theoretically, the optical bandwidth >300 GHz is predicted due to the optimized velocity matching between light and RF waves. Applications convince that the EO polymer modulator is one of the few possible solutions to simply provide the increased underlying symbol rates over 100 Gbaud. Recently, polymer modulators have further enhanced their inherent advantages such as high thermal resistance (>190°C), temporal stability (105°C longer than 2,000 hours [6]), and high-temperature operation (up to 110°C [7]). We showed that the EO polymers with enhanced thermo-physical property are alternative to the commonly used organic EO materials. To the best of our knowledge this is the highest temperature resistance for the polymer modulator technology compared with previous organic EO devices.

In this paper, we expand our earlier works about the high-speed EO polymer modulator and present the efficient on-off keying (OOK) signaling with a data rate up to 120 Gb/s with a drive voltage swing of 1.9 V. The high-speed modulator is fabricated on a silicon-on-insulator (SOI) waveguide with high-efficient EO polymer. To verify the high-speed modulation, the eye-diagrams, Q factors, and bit-error rate (BER) of the generated OOK signals are measured at a speed up to 120 Gbit/s.

2. Experimental and Results

Fabrication and Setup

The silicon-polymer hybrid modulator was fabricated via a standard lithography technique using EBL, ICP dry etching, and metal plating. More details about the fabrication can be found in reference [8]. Our fabricated Mach-Zehnder modulator comprised silicon core and EO polymer cladding, 8.0 mm-long phase shifters, and patterned gold strip lines serving as the traveling-wave electrode.

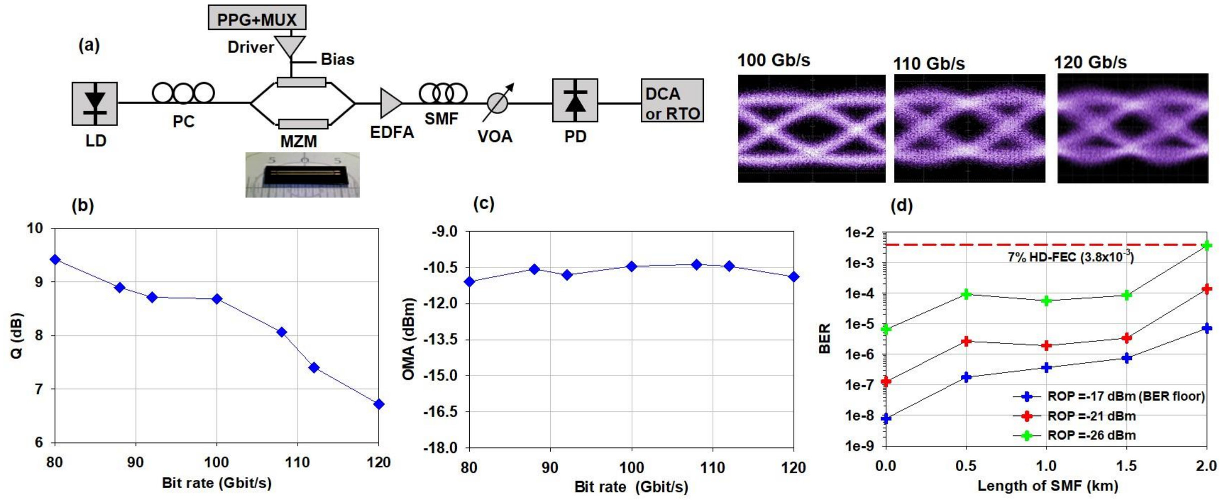

Fig. 1. (a) Set up for the high-speed data transmission measurement. The measured eye patterns of 100 Gb/s, 110 Gb/s, and 120 Gb/s OOK are shown. (b) Q factor vs. OOK bit rate, (c) OMA vs. OOK bit rate, and (d) BER for 100 Gb/s OOK vs lengh of SMF

The modulator allows a push-pull operation when applying drive voltages to the two arms of MZM. The measured modulation efficiency is 1.6 V·cm at the laser wavelength of 1,550 nm. In Fig. 1(a), two 60 Gb/s electrical PRBS streams with a length of 2^{15}-1 generated from a PPG are fed into MUX to generate a 120 Gbit/s NRZ signal. The signal is then amplified using a linear wideband amplifier and applied to the one arm of the MZM. The V_{pp} value is adjusted between 1.4~2.9 V_{pp}. The modulated optical output is amplified by an EDFA, and optical noise is eliminated using a band pass filter before connecting into a high-speed photodetector (PD).

High-Speed Signal Operation

With a peak-to-peak drive voltage of 1.9 V_{pp}, the measured optical eye-diagrams for 100-120 Gb/s OOK were recorded and shown in Fig 1 (a). It can be seen that the optical eyes are clean and open, which are relevant to the high bandwidth property of the fabricated silicon and polymer hybrid modulator. The measured Q factor and OMA at various bit rates are shown in Fig. 1(b) and 1(c). The Q factor decreases as increasing the bit rate, but no abrupt drop of Q factor can be seen up to 120 Gbit/s. The 120 Gb/s OOK transmission still has the Q factor of 6.7 dB. Allowing signal deviation characterization under Gaussian thermal noise, BER can be obtained as 1.3×10^{-6} . On the other hand, OMA is kept constant in the same data range. Based on the Q metric and assuming that the OMA is a fixed quantity, it is clear that the measured OOK signal is directly influenced by the signal noise variance. The metric predicts the BER for OOK signaling with sufficiently below 7% HD-FEC threshold (3.8×10^{-3}). In order to characterize the optical link performance, the BER after the single mode fiber transmission is tested as shown in Fig. 1(d). The fiber link consists of up to 2.0 km SMF. The back-to-back (BTB) performance is also shown as comparison. For the BTB case, a BER floor of 1×10^{-8} was obtained with the received optical power regime above -17 dBm. The BER depends on the revived optical power at PD and the fiber length. After 0.5 km, 1.0 km, 1.5 km, and 2.0 km fiber transmissions, BER penalty increases two or three order of magnitude compared to BTB performance. However, BER performance are all measured below the 7% HD-FEC threshold. The 2.0 km transmission is the worst among the four different testing, the receiver sensitivity at 7% HD-FEC threshold is -26 dBm.

3. Conclusions

We have experimentally demonstrated up to 120 Gbit/s OOK using SPH modulator. The waveguide is optimized to perform efficient EO property and high frequency response, showing high-spped OOK, low drive voltage, and small BER properties. Operation using PAM4 is promising in the next research step to reach 200 Gb/s signaling per lane [7].

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