

110 Gbit/s On-Off-Keying Based on High Temperature Resistant Polymer Modulator

(Invited paper)

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Abstract

A high-temperature resistant electro-optic (EO) polymer modulator is fabricated and demonstrated for generating reliable 110 Gbit/s OOK. The polymer is performed on the silicon Mach-Zehnder interferometer toward possible hybrid silicon and polymer photonic platform. We demonstrated high-bit rates signalling with low BER properties below FEC threshold. Because of the high thermal-stability of the EO polymers, negligible degradation of modulations was observed up to 90°C

Keywords: polymer modulator, silicon waveguide, on-off-keying, PAM4

1. Introduction

Recent progress of highly efficient and high-speed electro-optic (EO) modulator technology has received intensive research attentions in microwave photonics and fiber-optic networks. Among the different types of materials used in the modulator, the EO polymer offers intrinsic advantages such as a large EO coefficient ($r_{33} > 100$ pm/V), low dielectric constant and loss, and excellent compatibility with other materials and silicon substrates. Therefore, the EO polymer modulators open up a variety of opportunities for realizing unique wideband applications. In particular, achieving higher baud rates is an important objective toward optical interconnection at short-reach applications, so that polymer modulator might be a cost-effective 100G serial solution [1]. To date, the EO polymer modulators have shown outstanding performance such as high data rate transmission, low-power consumption, and easy integration to other substrates in a form of thin film polymer modulator [2], organic-silicon hybrid [3], or traveling-wave polymer on silicon waveguide [4]. The low fabrication cost and high yield of the polymer device is another advantage as a cost-effective solution to high-volume production of assembled optical transceivers. The progress makes the polymer device as one of the few possible solutions to realize over 100 Gbaud high-speed signalization. It meets the critical demand in the emerging optical interconnects for short-reach and datacenter networks. To further highlight the superior of EO polymer modulator, as another aspect, the environmental stability is vitally important to be urgently investigated. Telcordia GR468-CORE defines the temperature condition of 85°C for 2,000 hours as a standard in industrial applications. Clearly using the EO polymer with enhanced thermo-physical resistance is a simple solution to pass such environmental tests. We have recently shown that side-chain EO polymers having the glass transmission temperature (T_g) of over 180°C are alternative to the commonly used organic EO materials [5]. The enhanced temperature stabilities of the modulators showed invariable EO coefficients and frequency response up to 40 GHz [5,6].

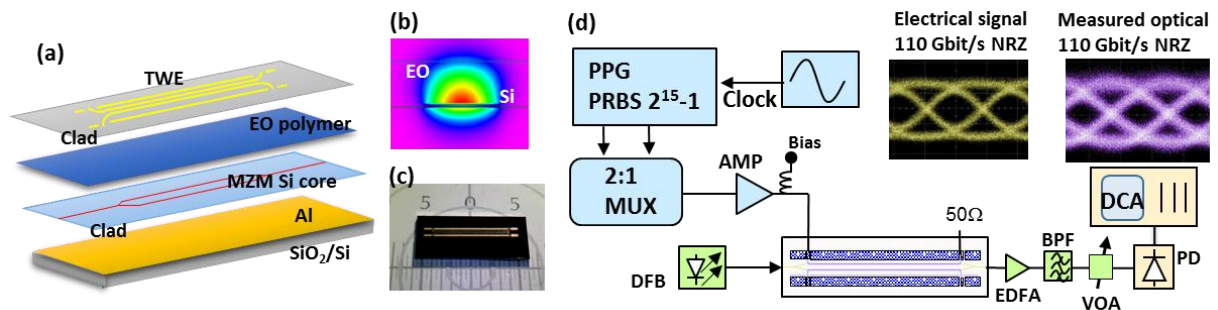


Fig. 1 The hybrid silicon and EO polymer modulator and high-speed modulation. (a) The layer-by-layer structure of the MZI waveguide, consisting of the bottom Al electrode, 50 nm-thick and 2 μ m-wide Si core, EO polymer, SiO₂ resin claddings, and traveling-wave electrode (TWE). (b) The calculated modal distribution indicating a part of the optical field penetrates into the EO polymer. (c) A photo picture of the signal MZI modulator having a 8 mm-long TWE. (d) Set up for the high-speed data transmission measurement. The high-speed PPG and 2:1 MUX are used to apply the electrical signal to the MZI modulator. The laser light from the DFB at the wavelength of 1550 nm is coupled to the waveguide, and output light is conducted to the photodetector after amplification using EDFA and passing a BPF and VOA. For high-speed modulation, 90-110 Gbit/s OOK signal is applied to the one electrode of two MZIs, and optical diagrams are measured by using a DCA. Typical electric drive signal with $V_{pp}=1.5-2.5$ V and the measured optical signal are shown as the eye-diagrams.

In this paper, we expand our earlier works about the high-thermal stable EO polymer application [7] and present the high-speed on-off-keying (OOK) generation with a signalling rate of up to 110 Gbit/s. The EO polymer modulator is fabricated on a Mach-Zehnder interferometer (MZI), which consists of the hybrid silicon and polymer waveguide and RF traveling-wave electrodes. To verify the high-speed operation of the polymer modulator, the S-parameter frequency response of the fabricated polymer modulator, and the eye-diagrams and Q factors of the generated OOK signals when operating the modulator at speed up to 110 Gbit/s are measured.

2. High-speed data transmission and high-thermal stability testing

A network analyser is used to characterize the frequency response of the fabricated EO polymer MZI modulator. The measured S21 parameter indicates the 3-dB bandwidth of around 60 GHz. Though the used analyser has limited frequency bandwidth to characterize response, the 6-dB bandwidth of the polymer modulator is certainly presumed over 70 GHz, showing the capability of >100 Gbaud signalling. Figure 1d represents the experimental setup for testing the high-speed serial data modulation. The CW light from the laser with the wavelength of 1,550 nm is modulated by applying the electric driving signals. Two ~55 Gbit/s electrical pseud-random bit sequence (PRBS) streams with a length of $2^{15}-1$ are firstly generated from a pulse pattern generator. Two electrical streams are then fed into an electrical multiplexer to generate a ~110 Gbit/s data signals. The signal is amplified using a linear wideband microwave amplifier and applied to the one arm of the MZI. A 50 Ω resistor was connected on the output end of the traveling-wave electrode for termination. Typical fiber-to-fiber insertion loss is 10~12 dB. The modulated optical signal is amplified using an EDFA and optical noise is eliminated using a band pass filter before connecting it to a photodetector. With a peak-to-peak drive voltage of 1.5-2.5 V_{pp}, the measured optical eye-diagrams of 100 and 110 Gbit/s OOK data are recorded by using a digital communications analyzer (DCA) (Fig. 2a and 2b). It can be seen that the optical eyes are clean and open, which are relevant to the high bandwidth property of the EO polymer MZI modulator. The modulation performance is assessed using the Q-factor metric assuming the Gaussian noise limited detection of two levels noise variance of the received signal values. The metric is well suited for binary on-off signalling, thus bit error rates (BER) can be evaluated from the Q analysis. It should be noted that the obtained BER is theoretically optimized to give the minimized value. Figure 2c shows the converted curves of BERs versus the received optical power at 90, 100 and 110 Gbit/s signalizations. To correct these data, the measurements are in back-to-back and the receiver is preceded by a variable optical attenuator (VOA). For low signal power, the receiver response is fully linear allowing the receiver operation under Gaussian thermal noise. We observe that 90-110 Gbit/s OOK transmission is able to yield a BER that is below the DH-FEC threshold of 3.8×10^{-3} .

To investigate the modulator's performance dependence on the temperature, Q factors at 100 Gbit/s data rate are measured at different temperatures in Fig. 2d. A reduction of Q factor is gentle when the temperature is increased up to 90°C. Though disordering of the eye diagram is found at higher temperature, the eye diagram is completely recovered to its original activity when the device is cooled down to room temperature. Assuming that the significant degradation of the EO activity is negligible in the wide temperature range, the measured decrease of the Q factor for 100 Gbit/s at higher temperatures might be attributed to other loss factors.

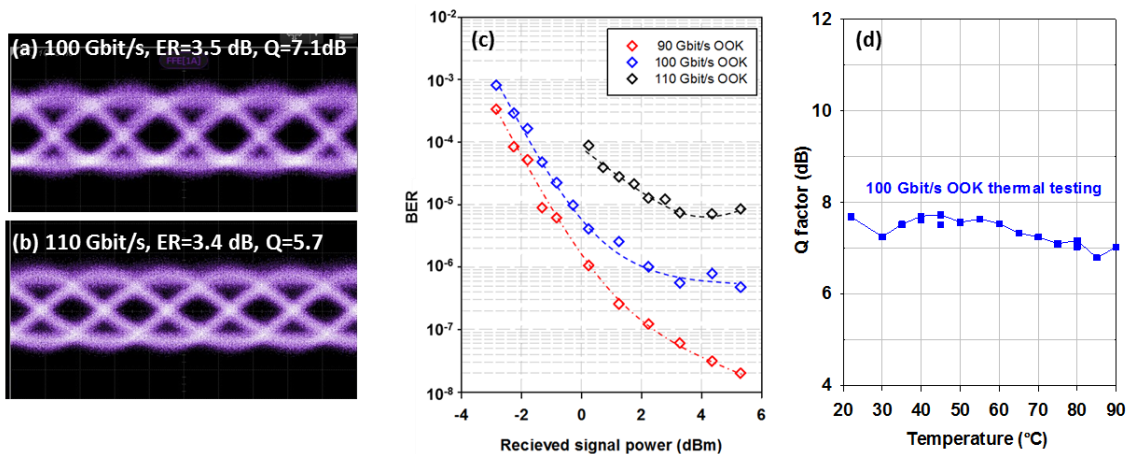


Fig. 2 (a and b) The measured optical eye-diagrams of 100 Gbit/s and 110 Gbit/s OOK transmissions. (c) OOK BER of the modulator for varying received signal power running at 90, 100, and 110 Gbit/s. (d) Thermal stability test of the 100 Gbit/s modulation. The temperature is ranged up to 90°C.

Conclusion

We have demonstrated >100 Gbit/s transmitters using a wideband hybrid silicon and polymer EO modulator. The hybrid modulator was optimized to perform the large bandwidth and low-driving voltage properties. With the development of high- T_g polymers, it reveals a long-term high temperature stability and thermal resistance with high bit rate operation. The measured Q factor variation of 100 Gbit/s OOK over the temperature range of 20-90°C was minimum. The device can be further improved to reveal the similar thermal resistant for faster modulations.

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