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High-speed Polarization-insensitive Electro-absorption Modulator Module with Low-driving Voltage

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Abstract We present a polarization-insensitive electro-absorption modulator module operating at a low driving voltage of ~1.5 Vpp from 1540 nm to 1560 nm. The module shows a clear 50 Gb/s PAM-4 eye pattern with <1.6 dB TDECQ for a dynamic outer extinction ratio of more than 8 dB.

1 Introduction

High-speed optical modulators are widely used in optical communication and interconnect systems, covering a wide range of applications for the 1550- and the 1300-nm optical windows. Compared with Si-based microring modulator(MRM)[1]/ Mach-Zehnder modulator (MZM)[2,3] and lithium niobite-based modulators[4], the III-V-based electro-absorption modulators (EAM) have the advantage of low driving voltage, insensitive polarization, easily operation, and monolithic integration of semiconductor lasers[5,6,7,8]. In 2021， we reported a 25 Gb/s polarization-insensitive electro-absorption modulator(PIM) by strain tailoring of the multiple-quantum-wells (MQWs) and dedicated waveguide design[7]. Here, we further optimize the device structure to improve its performance and package it to meet the application of 50Gb/s optical communication

The PIM module shows the characteristics of low driving voltage and low polarization sensitivity in a wide wavelength range of 1540-1560 nm. Clear openings of eye patterns in the modulation format of 25 Gb/s NRZ and 50Gb/s PAM-4 are also demonstrated.

2 PIM module structure

Fig.1 shows the photograph of a PIM module with a flexible printed circuit (FPC) interface. It consists of an optical coupling part with lenses and fiber collimators on both the input and output side, a temperature controlling part with thermo-electric cooler (TEC) and thermistor, and a high-frequency electrical part with microstrip line fabricated on a flexible printed circuit (FPC) and AlN ceramic carrier. On the input side, light from the single-mode fiber was first collimated by a fiber collimator, then focused by an aspherical lens, and finally coupled to the PIM chip. Light from the PIM chip is first converted into parallel light by the aspheric lens and then goes into single-mode on the output side with the help of fiber collimator. The PIM chip and aspherical lenses were mounted on a TEC to ensure the temperature stability of modulators. Microstrip lines fabricated on the FPC and AlN ceramic are used to feed the high-speed electrical signal, and a 50-ohm resistor and a 10-nf capacitor were shunted with the PIM chip for impendence matching and DC blocking by wire bonding, respectively.

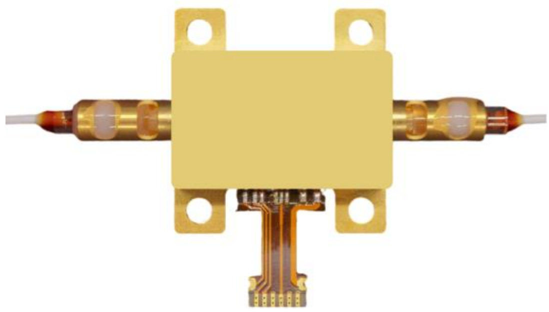

Fig. 1: Picture of a packaged PIM module with a FPC interface

3 PIM module performance

The PIM chip in the module has a length of 125 μm and a ridge width of 2.5 μm. More details about the design and fabrication process of the modulators can be found in ref[7]. The polarization state of the incident light (from Santec TLS-550, and the output power was maintained at 10 dBm for different wavelengths) was controlled by a polarization controller. The TE or TM-polarized light was used to evaluate the performance of the PIM module (TE and TM-polarizations represent the polarization state of the optical signal transmitted through the module at zero bias with a maximum or minimum received power). Fig.2 shows the static extinction characteristics with respect to bias voltage for different wavelengths at both TE and TM polarizations. An extinction ratio of over 20 dB is achieved at -3 V bias voltage for the 1540-1560 nm wavelength range. Besides, the PIM module shows a low polarization sensitivity in a wide wavelength range and a wide bias voltage range. At the wavelength of 1540, 1550, and 1560 nm, the polarization sensitivity is kept around 1 dB until the bias voltage up to -2V, -2.2V, and -2.6V, respectively.

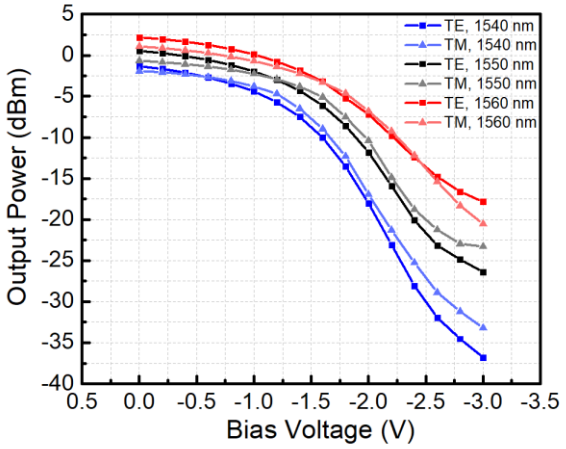

Fig. 2: Static extinction ration of the PIM module versus reverse bias voltage for several wavelengths at TE and TM polarizations

The frequency characteristics of this module under different bias voltages are shown in fig.3 (measured by Anritsu MS4647B). Due to the packaging parasitic parameters, there is an E/O response dip (~2.5 dB) in the frequency range of 16 GHz to 20 GHz. The E/O response curves only exhibit a 3-dB small-signal modulation bandwidth of ~16 GHz. Fortunately, the 6-dB bandwidth is up to ~24 GHz without severe fluctuation in the dipping frequency range.

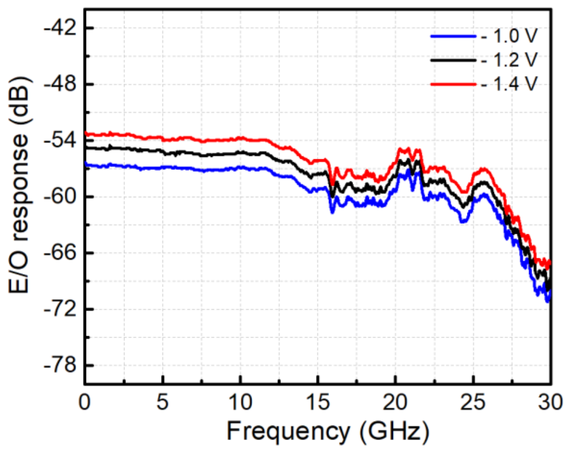

Fig. 3: Measured small-signal frequency responses of the PIM module at different bias voltage.

Fig.4 shows the measured 25 Gb/s non-return to zero (NRZ) back-to-back (BTB) eye patterns for different wavelengths (raw(a) 1540 nm, raw(b) 1550 nm, and raw(c) 1560 nm) at both TE(column(i)- and TM(column (ii)-polarizations. Pseudo-random bit sequence (PRBS) data patterns with a length of 2^{31}-1 from a signal quality analyzer (Keysight M8045A) were used to modulate the PIM module, and the modulated optical signal was recorded by using a broadband sampling oscilloscope (Keysight 86100D). As can be seen, clearly opened eye diagrams were obtained at both TE- and TM-polarizations in the wavelength range of 1540–1560 nm. In the measurement, the bias voltage and the modulation voltage swing (Vpp) were set to (-1.4 V, 1.4V pp), (-1.5 V, 1.4 Vpp), and (-1.7 V, 1.5 Vpp) for 1540 nm,1550 nm, and 1560 nm, which were slightly varier with each other to satisfy different wavelengths. The dynamic extinction ratio of the above mentioned three operating states corresponded to (9.3 dB, 8.2 dB), (8.9 dB, 8.0 dB) and (8.1 dB, 9.3 dB) for TE- and TM-polarizations, respectively. With the proper bias points and modulation voltage swings chosen for different wavelengths, dynamic polarization sensitivity of less than 1.2 dB was obtained in 1540-1560 nm. Over 8 dB dynamic extinction ratio for TE- and TM polarizations was obtained at a driving voltage of less than 1.5 Vpp in a wide wavelength range. It might be possible to drive the PIM module directly through CMOS output, e.g., from a digital signal processor (DSP) without an external driver, thus decreasing the power consumption.

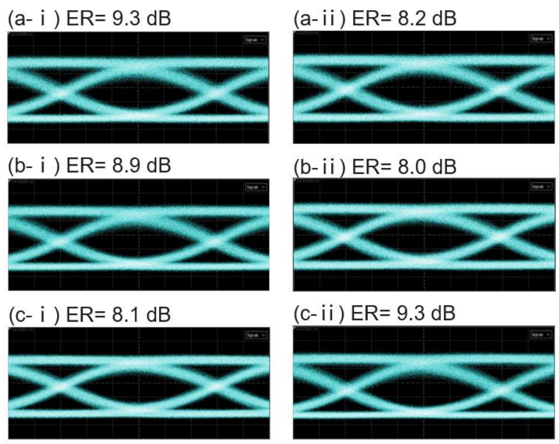

Fig. 4: 25 Gb/s NRZ eye patterns (BTB) of the module working at (a) 1540 nm, (b) 1550 nm, and (c) 1560 nm, respectively. Column (i) indicates eye patterns of the incident light at TE-polarization; Column (ii) indicates eye diagrams of the incident light at TM-polarization.

Fig. 5 shows the received BTB optical PAM-4 eye patterns at a bit rate of 50 Gb/s for the above wavelengths (raw(a) 1540 nm, raw(b) 1550 nm, and raw(c) 1560 nm) at both TE(column (i))- and TM(column (ii))-polarizations. To obtain an outer ER larger than 8 dB with a polarization sensitivity less than 1 dB, the bias voltage and the

Vpp were set as (-1.5 V, 1.4 Vpp), (-1.5 V, 1.5 Vpp), and (-1.7 V, 1.5 Vpp) for 1540 nm,1550 nm, and 1560 nm, respectively. Due to the frequency response dipping in the frequency range of 16 to 20 GHz, those eye patterns were optimized by the inbuilt linear equalizer of the oscilloscope with 5 taps. Those optimized eye diagrams show three clearly opened optical eyes, and the TDECQ is less than 1.6 dB in a wide wavelength

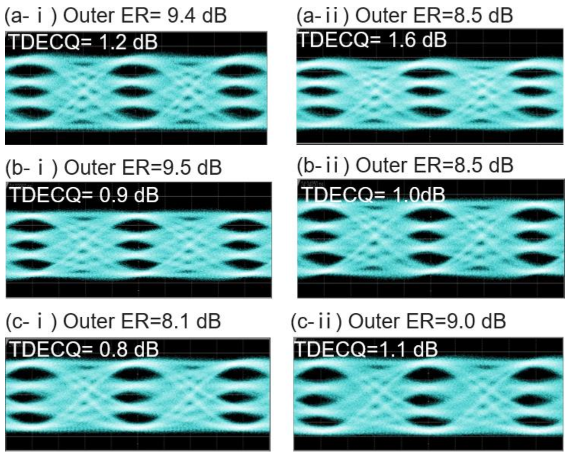

Fig. 5: 50 Gb/s PAM4 eye patterns (BTB) of the module working at (a) 1540 nm, (b) 1550 nm, and (c) 1560 nm, respectively. Column (i) records eye patterns of the incident light at TE-polarization; Column (ii) records eye diagrams of the incident light at TM-polarization.

range at both TE- and TM- polarizations.

4 Conclusions

In conclusion, we report a high-speed PIM module operating in a wide wavelength range with a low driving voltage. The PIM module remains low static polarization sensitivity of less than 1 dB until the bias voltage up to -2 V,-2.4 V, and -2.6 V for 1540 nm,1550 nm, and 1560 nm, respectively. The 3-dB small-signal modulation bandwidth is ~16 GHz and the 6-dB bandwidth is up to ~24 GHz without severe fluctuation. The 25 Gb/s NRZ eye diagrams are opened with the dynamic extinction over 8 dB and polarization sensitivity less than 1.2 dB at a driving voltage less than 1.5 Vpp for the wavelength range of 1540-1560 nm. It is worth mentioning that the optimized 50 Gb/s PAM-4 eye patterns are also clearly opened with an outer ER larger than 8 dB(polarization sensitivity less than 1 dB) and a TDECQ less than 1.6 dB. Those results show that the PIM module can support 50 Gb/s data transmission in a wide wavelength range with low polarization sensitivity and low driving voltage.

5 Acknowledgements

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6 References

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