Wide Wavelength Polarization-insensitive Electro-absorption Modulator with Low-driving Voltage

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Abstract We present a 25 Gb/s wide wavelength polarization-insensitive electro-absorption modulator (PIM) operating at a low-driving voltage. Over 8 dB dynamic extinction ratio was obtained in the wavelength range of 1540-1560 nm with polarization sensitivity around 1.1 dB, at the driving-voltage as low as 1.8 Vpp.

1 Introduction

Electro-absorption modulator (EAM) is a key device in high-speed optical networks for optical signal modulation and processing due to its compactness and ease of operation. In optical networks, especially for cloud radio access networks[1,2], it is highly desirable that the EAM can work in a wide wavelength range with polarization insensitivity or low polarization sensitivity.

There are several ways to achieve polarization-insensitive EAM (PIM): strain-compensated multiple-quantum-wells (MQWs) with tensile wells and compressive barriers[3], modified potential distribution wells, whose effective width depends on the mass of the holes[4], parabolic quantum wells [5]. Among these device structures, the strained compensated MQWs structure has been widely used due to its simple growth procedure by metal-organic chemical vapor deposition (MOCVD)[3,6-7]. In ref.[5], the polarization sensitivity was less than 1 dB, however, the extinction ratio was only 3 dB. In ref.[6], a driving voltage of 1.2 V is achieved for a static extinction ratio of 20 dB at the single wavelength of 1.55 µm. However, the polarization sensitivity is still larger than 4 dB for the bias voltage which is in the range of 0 V to -1.2 V.

To take further advantage of the PIM, low voltage driving is a key technology in terms of low power consumption and high port density. With a low driving voltage, it might be possible to drive the PIM directly through CMOS output, e.g., from a digital signal processor (DSP), without an external driver in between[8].

In this paper, we report a wide wavelength 25 Gb/s PIM with low driving voltage. By optimizing the strain of the MQWs and the doping concentration of the upper and lower graded-index, separate confinement heterojunction (GRIN-SCH) layer, a dynamic extinction ratio of over 8 dB was achieved in the wavelength range of 1540 nm and 1560 nm with polarization sensitivity around 1.1 dB, at the driving voltage as low as 1.8 Vpp.

2 Device Design and Fabrication

The epilayers used for the PIM are InGaAlAs-based strained MQWs on an n-InP substrate grown by MOCVD. The active region consists of multiple periods of 10 nm thick, tensile strained wells, and 6 nm thick, compressively strained barriers. The photoluminescence peak of the complete MQWs stack is 1.47 µm. The core is sandwiched by two 35 nm thick GRIN-SCH layers, and 25 nm of the 35 nm lower/upper grin-SCH was n/p doped at the n-buffer and p-cladding side, respectively. The total thickness of the intrinsic region is about 200 nm. The partial dopped GRIN-SCH layers help to increase the modulation efficiency. The upper GRIN-SCH layer was topped with a 1.6 µm-thick p-InP cladding layer and a 0.2 µm-thick p^+-InGaAs contact layer. A 2-µm-wide ridge-waveguide was first formed by a combination of wet and dry etching, and then a 10-µm-wide deep-ridge was etched by removing the active layer. Polarization insensitive absorption was demonstrated by the strained MQWs and the specially designed ridge-waveguide. The whole ridge-waveguide was buried by polyimide, which helps to reduce the parasitic capacitor of the contact pad. The devices were then cleaved, and both facets were coated with anti-reflection films. Fig.1 shows the microscope photograph of the fabricated PIM chip. It is with a clean device surface.

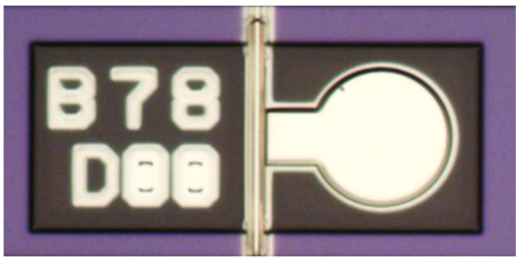

Fig. 1: Optcial microscope photograph of the proposed polarization-insensitive electro-absorption modulator chip

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3 Experimental results

The PIM chip was mounted on a ceramic carrier and measured in a room environment without temperature control. TE- or TM-polarized light from a tunable laser (Santec TLS-550) has been coupled in and out of the PIM by a pair of tapered-lens fibers, respectively. The output power of the tunable laser was maintained at 13 dBm. The fiber-to-fiber transmission versus the reverse bias voltage of a 150-μm-long PIM for different wavelengths at both TE and TM-polarizations were illustrated in Fig.2. As shown in Fig.2, the static extinction ratio of the device is more than 20 dB in the wavelength range of 1540 -1560 nm. It shows low dependence on the polarization states of the incident light. In the reverse bias range from 0 to -2V, the polarization sensitivity is less than 1 dB at 1550nm and 1560 nm and less than 1.7 dB at 1540 nm for TE- and TM- modes.

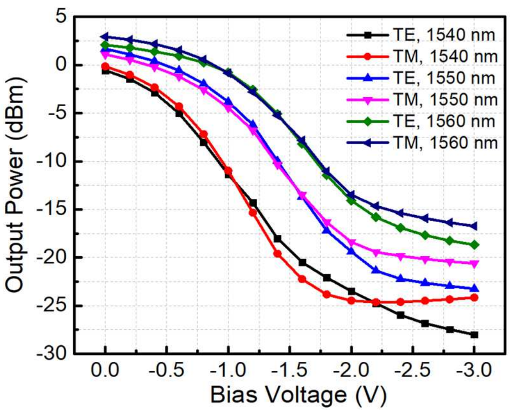

Fig. 2: Static extinction ration of a 150μm-long modulator versus reverse bias voltage for several wavelengths at TE and TM polarizations

The small-signal frequency response of the PIM was measured by a vector network analyzer (Anritsu MS4647B). A 50-ohm thin-film TaN resistor on the ceramic carrier was shunted with the PIM for impendence matching, and a GSG thin-film transmission line was used to match the RF probe. Fig.3 shows the small-signal frequency responses of a 150-μm-long, 2-μm-wide ridge-waveguide PIM at a bias voltage of -1 V, a 3-dB frequency bandwidth of about 20 GHz was obtained. The small-signal modulation bandwidth of the PIM can be further improved when materials with lower dielectric constant are used underneath the metal pads.

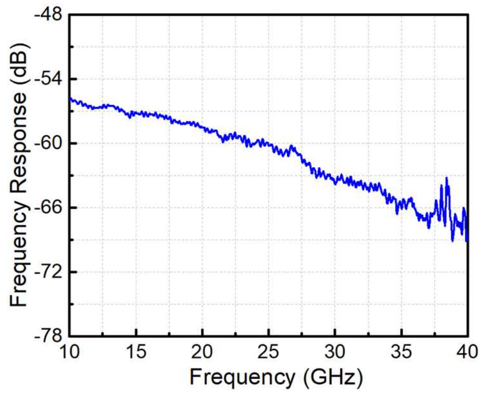

Fig. 3: Measured small-signal frequency responses of the 150-μm long PIM at a bias voltage of -1 V

The back-to-back (BTB) eye diagrams for different wavelengths at TE- and TM-modes were measured by using a signal quality analyzer (Keysight N4960A) and a digital sampling oscilloscope (Keysight 86100D). Non-return to zero (NRZ) pseudo-random bit sequence (PRBS) data patterns with a length of 2^{31}-1 were used to modulate the PIM. Fig.4 shows the BTB 25 Gb/s eye diagrams at three different wavelengths of 1540nm, 1550nm and 1560nm for both TE- (column (i)) and TM- (column (ii)) modes. As can be seen, clearly opened eye diagrams were obtained at both TE- and TM-modes in the wavelength range of 1540–1560nm. In the measurement, the bias voltage and the modulation voltage swing (Vpp) were set to (-0.8V, 1.5Vpp), (-1.0V, 1.6Vpp) and (-1.2V, 1.8Vpp) 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 (8.1dB, 9.0 dB), (8.2 dB, 8.0 dB) and (9.5 dB, 8.4 dB) for TE- and TM-modes, respectively. With the proper bias points choosing for different wavelengths, polarization sensitivity less than 1.1 dB was obtained in the wavelength range of 1540-1560nm. Over 8 dB dynamic extinction ratio for both TE- and TM- modes were obtained at a driving voltage of 1.5 Vpp,1.6 Vpp, and 1.8 Vpp for 1540 nm, 1550 nm, and 1560 nm. The ability

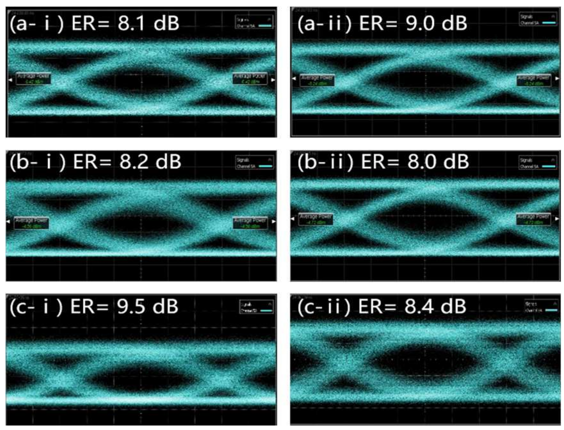

Fig. 4: BTB eye diagrams of the PIM modulated by a 25Gb/s signal at a wavelength of (a) 1540 nm, (b) 1550 nm, (c) 1560 nm, respectively. Column (i) records eye diagrams of the incident light at TE-mode; Column (ii) records eye diagrams of the incident light at TM-mode

of low driving voltage to achieve a high extinction ratio was beneficial from the partial doped lower/upper GRIN-SCH layer.

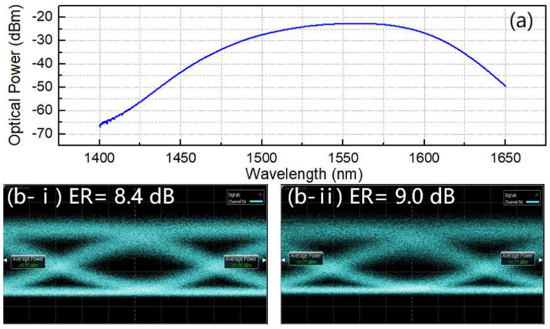

Fig. 5: (a) Optical spectrum of the ASE source. BTB eye diagrams of the ASE source as modulated light at (b- i) quasi-TE mode and (b- ii) quasi-TM mode

As shown in Fig. 5(a), an amplified spontaneous emission (ASE) source with a 1 dB spectrum bandwidth of 50 nm centered at 1550 nm was also used as the modulation source to verify the polarization sensitivity. Fig.5 (b) shows the eye diagrams of the ASE source as the modulated light with a bias voltage and modulation swing of -1.1V and 2.2Vpp. For quasi-TE (Fig.5 (b-i)) and quasi-TM (Fig.5 (b-ii)) modes, the dynamic extinction ratio is 8.4 dB and 9.0 dB, which demonstrated the designed PIM insensitive to the polarization state in a wide wavelength range. (Quasi-TE and quasi-TM modes represent the polarization state of the ASE source transmitted through the device (zero bias) with a maximum or minimum received power).

4 Conclusions

In conclusion, we have fabricated a polarization-insensitive InGaAlAs-based strained MQW electro-absorption modulator operating in the wavelength range of 1540-1560 nm. With an optimal design of the MQWs material and the waveguide geometry, a 150-μm-long PIM remains static polarization sensitivity less than 1.7 dB until the bias voltage up to -2 V. The modulation bandwidth up to 20 GHz, and the 25 Gb/s eye diagrams are opened with the dynamic extinction over 8 dB and polarization sensitivity less than 1.1 dB at a driving voltage less 1.8 Vpp for the wavelength range of 1540-1560 nm. These results show that with proper design, polarization-dependent extinction ratio can be optimized and obtain higher speed, lower driving voltage, and larger extinction ratio for optical fiber communication applications.

5 Acknowledgements

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