Compact $LiNbO_3$ Optical Modulator for Polarization-division-multiplexing RZ-DQPSK

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Abstract *An integrated PDM-RZ-DQPSK modulator was developed for the first time with a small bend radius and low-loss, low-crosstalk intersecting U-turn waveguides. This design enables low PDL of less than 0.3 dB*

Introduction

$LiNbO_3$ Mach-Zehnder Interferometer (MZI) optical intensity modulators[1] are currently key devices in the construction of long-haul WDM high-bit-rate optical communication systems because of their low insertion loss, low-frequency chirp, and wavelength independent characteristics. Recently, optical transmission systems using multi-level modulation formats such as Differential Quadrature Phase-Shift-Keying (DQPSK)[2], are actively studied for next generation systems. Modulators for these multi-level modulation formats consist of multiple MZI modulators. Thus, to realize these modulators, it is important to reduce size by integrating modulators. We developed a low drive-voltage DQPSK modulator[3] and compact RZ-DQPSK modulator using a U-turn waveguide[4].

In this work, we have developed a compact modulator for a polarization-division-multiplexing RZ-DQPSK (PDM-RZ-DQPSK).

Device design

Figure 1 shows the design of our PDM-RZ-DQPSK modulator. It consists of two DQPSK modulators and an RZ modulator. The DQPSK modulator consists of two inner MZI modulators in an outer MZI waveguide. The two outputs of an RZ modulator are complimentary signals, in-phase and out-phase. By synchronizing each RZ signal with each DQPSK modulator, it is possible to achieve a common RZ modulator. The two outputs of DQPSK modulators are combined by PBC. The polarization-division-multiplexing output signal becomes interleaved. To

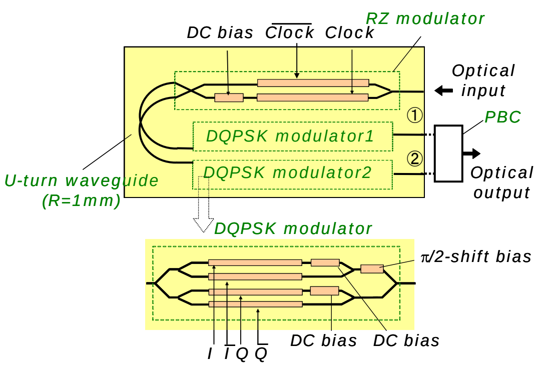

Fig. 1: Device design

realize this compact PDM-RZ-DQPSK modulator, the two U-turn waveguides are required to intersect.

Figure 2 shows our intersecting U-turn waveguide structure. The bend radius of each U-turn waveguides is 1.0 mm. To reduce excess loss of the intersection, we considered the structure of the narrower gap of the groove at a cross point

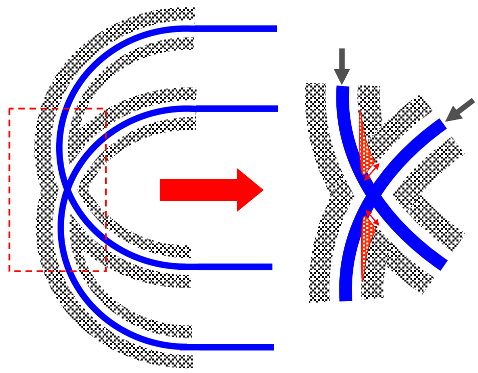

Fig. 2: Intersecting U-turn waveguide

Characteristics of the developed PDM-RZ-DQPSK modulator

First, we measured the characteristics of the intersecting U-turn waveguides only, which is less than -45 dB crosstalk and 0-0.2 dB excess loss. Second, we evaluated the characteristics of the PDM-RZ-DQPSK modulator using the intersecting U-turn waveguide. Figure 3 shows the wavelength dependency of insertion loss and optical crosstalk of the two outputs before PBC.

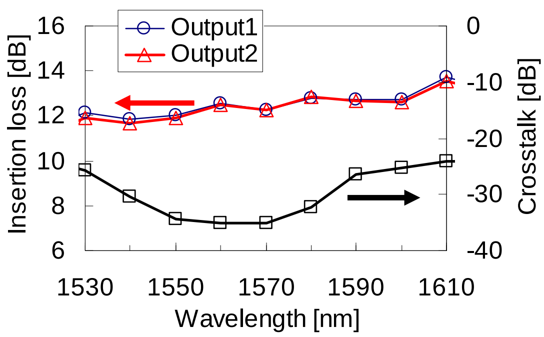

Fig. 3: Wavelength dependency of insertion loss and crosstalk

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The difference between the two insertion losses induces the polarization dependent loss (PDL), and the crosstalk induces the optical crosstalk between polarizations. In the C+L-band, the insertion losses are about 12 dB and the difference between insertion losses is less than 0.3 dB. The optical crosstalk is less than -24 dB. Optical frequency responses are shown in Fig. 4. The bandwidths for the eight ports are broader than 30 GHz, which is sufficient for DQPSK modulation over 50 Gb/s.

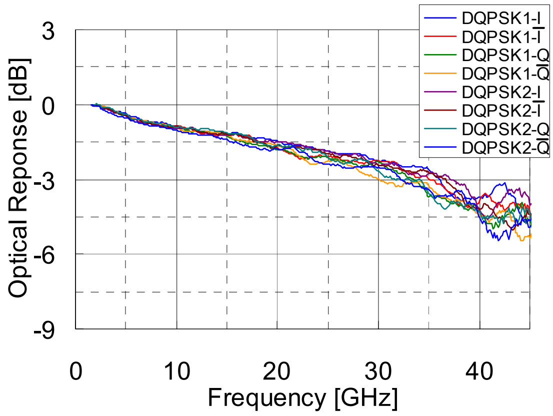


Fig.4: EO characteristics

Figure 5 shows electrical crosstalk between a DQPSK modulator and an RZ modulator. The crosstalk, which is the electrical power transmitted between the nearest ports of RZ and DQPSK1, is below -25dB in a wide frequency range, showing that the separation between the DQPSK modulator and the RZ modulator is good enough to avoid waveform degradation due to integration. Additionally, we evaluated electrical crosstalk between two DQPSK modulators. The crosstalk, which is the electrical power transmitted between nearest ports of DQPSK1 and DQPSK2, is below -20dB in a wide frequency range.

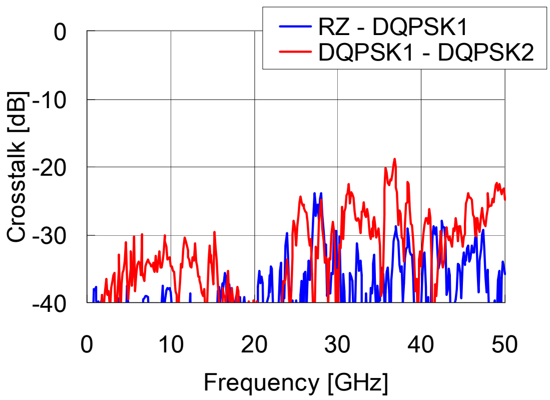
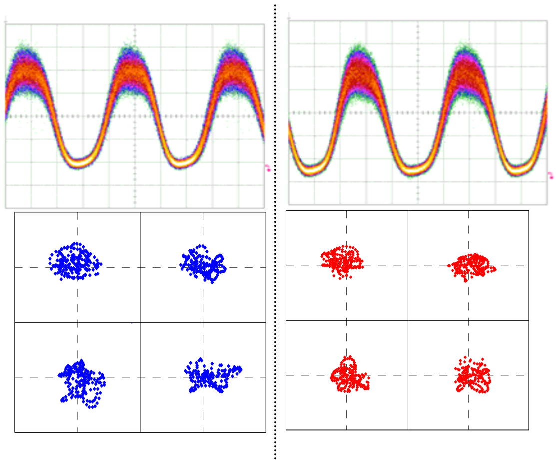


Fig.5: Electrical crosstalk

We then evaluated required drive-voltages for 50 Gb/s RZ-DQPSK modulation. The obtained drive-voltages are 3.5V for all eight DQPSK ports with 25 Gb/s NRZ driving signal and 3.7V for RZ pulse carver with 25-GHz dual-drive clock. This means our RZ-DQPSK modulator provides low drive-voltage operation.

Figure 6 shows two intensity eye patterns and constellations of 50-Gb/s DQPSK modulation at two outputs of our developed PDM-RZ-DQPSK modulator. The precise mapping of the trace to the QPSK constellation supports the excellent uniformity in frequency response and in loss characteristics among the four modulation arms.



(a) Output1 (b) Output2

Fig.6: 50-Gb/s optical waveforms and constellations of RZ-DQPSK for each output

Conclusions

We have developed a compact PDM-RZ-DQPSK modulator through the integration of a RZ modulator and two DQPSK modulators by using intersecting U-turn waveguide with low crosstalk. That design enables low PDL of less than 0.3 dB and low crosstalk of less than -24 dB. The two outputs of the modulator have the positive characteristics of 50-Gb/s RZ-DQPSK modulation. These results show that the modulator is suitable for 100-Gb/s PDM-RZ-DQPSK.

Acknowledgement

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