

40 Gb/s Low-drive-voltage LiNbO₃ Optical Modulator for DQPSK Modulation Format

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Abstract: Low-drive-voltage (3.5 V) and uniform modulation characteristics of MZIs were achieved with Z-cut dual-drive nested-MZIs structure and the wide-gap design between signal and ground electrodes, resulting in precise constellation mappings in 43 Gb/s DQPSK modulation.

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OCIS codes: (130.3730) Lithium niobate; (250.7360) Waveguide modulators

1. Introduction

LiNbO₃ Mach-Zehnder Interferometer (MZI) optical intensity modulators [1,2] are current 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 Differential Quadrature Phase-Shift-Keying (DQPSK) modulation format [3] is actively studied for the next generation systems with larger dispersion tolerance and higher spectral efficiency due to the narrower modulated optical spectrum. One of the key components to realize the DQPSK modulation is the optical modulators. In particular, low-drive-voltage is essential in practical use to reduce power consumption of driver circuits.

This paper reports development and fabrication results of DQPSK low-drive-voltage (3.5 V) LiNbO₃ modulators with Z-cut dual-drive nested-MZIs structure, which enables precise constellation mappings in 43 Gb/s DQPSK modulation.

2. Device design of DQPSK modulator

Figure 1 shows the basic design of our DQPSK modulator. It consists of two inner MZI modulators in outer MZI waveguide. The phase modulation of 0 and π with I- or Q-electrical-signal is realized with driving each inner MZI modulator at each null-bias point. By combining the two modulated light with $\pi/2$ phase shift in outer MZI, the 4-level phase modulation of 0, $\pi/2$, π , and $3\pi/2$ is obtained.

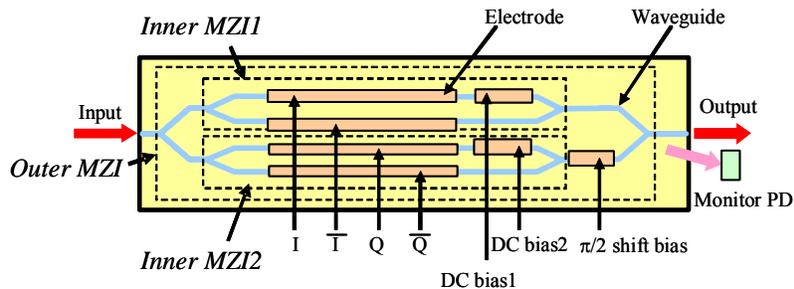


Fig.1 Device design

To realize DQPSK modulation, high drive-voltage with $2 \times V\pi$ is required because the phase modulation with the

MZI modulator is realized with driving at null-bias point. Moreover, the $V\pi$ increases because the waveguide structure with two inner MZIs and one outer MZI shortens the interaction length of the electrode and optical waveguide for modulation. The decrease of the drive-voltage is a big issue for practical use. To solve this issue, we adopted dual-drive structure for each inner MZI modulator using Z-cut LiNbO₃ substrate as shown in Figure 1. Low drive-voltage of $V\pi$ to each electrode is obtained with the complementary signal drive. Moreover, we introduced our electrode design technology for the low drive-voltage [4]. Wide-gap design between signal and ground electrodes and long interaction length of modulation reduces the $V\pi$ due to the reduction of electrode microwave loss.

Another issue for DQPSK modulation is precise mapping of the electrical signal to the optical phase and amplitude which influences to optical signal quality for phase modulation. The main causes of the mapping error with the devices are optical loss difference between two inner MZI modulators and difference of high frequency $V\pi$ by inequality of EO characteristics among four ports. Former causes imbalance combination of the I-modulated optical signal and the Q-modulated one. Latter causes inadequate optical amplitude and/or phase modulation in each inner MZI. In practical use, electrical signal input on one side is favorable to control delay difference between I- and Q-electrical-signal, which cause the difference among feeding electrodes of four electrical signal ports and dynamic $V\pi$ inequality by difference of microwave loss among four feeding electrodes. To solve the issue, we refined the waveguide fabrication process for optical loss uniformity, and electrode design for equalizing microwave loss in feeding electrode was introduced to achieve one-side signal inputs.

3. Characteristics of the DQPSK modulator

The insertion loss of our fabricated DQPSK modulator was as low as 5.5 dB. A high optical extinction ratio of outer MZI exceeding 30 dB was obtained, which shows excellent loss balance between the inner MZI modulators. An optical frequency response is shown in Figure 2. The EO bandwidths for four ports are broader than 25 GHz that is sufficient for 40 Gb/s-class DQPSK modulation. It should be noted that the difference of response among the four ports is below 1 dB within this bandwidth.

To evaluate required drive-voltage for 43 Gb/s DQPSK modulation, optical dynamic extinction ratios were measured by applying 21.5 Gb/s NRZ driving signal to one of the four ports with various voltages. The measurement was done by biasing the inner MZI at the quadrature point. Figure 3 shows the results. Low and almost the same drive-voltages of 3.5V for all four ports were attained. This means the DQPSK modulation is attainable with low drive-voltage of 3.5 V for each port with complementary dual-drives.

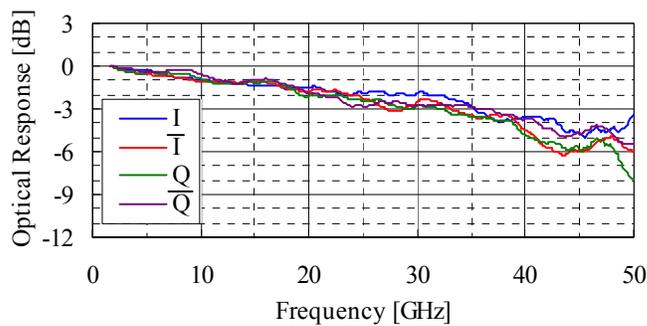


Fig.2 Optical Frequency Response

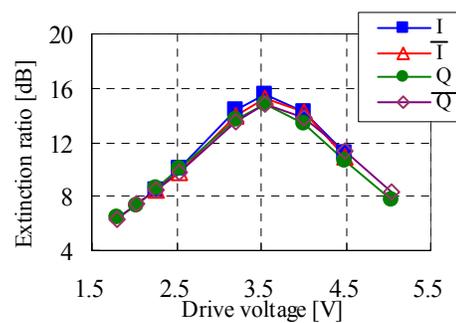


Fig.3 Drive-voltage vs. dynamic extinction ratio

Figure 4 shows an intensity eye pattern, a phase eye pattern, and a constellation of 43 Gb/s DQPSK modulation obtained by using an optical complex spectrum analyzer (APEX AP2440A). The precise mapping of the trace to the QPSK constellation supports the excellent uniformity of frequency response and of loss characteristics among the four modulation arms.

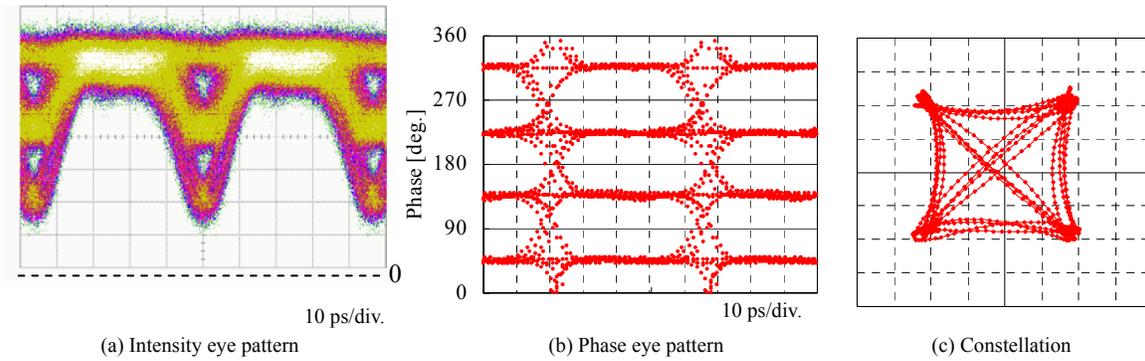


Fig.4 DQPSK modulation characteristics

The volume productivity of the device was evaluated by measuring the EO bandwidths for 50 fabricated test modules (Figure 5). The bandwidths exceeded 25 GHz for all modules, which are enough for 40 Gb/s-class DQPSK modulation. Reliability testing of our DQPSK modulator, to be reported else where, showed as high reliability as our conventional LiNbO₃ modulators, because the fabrication processes of the DQPSK modulators are based on that of established conventional intensity modulators.

Figure 6 shows the outer view of the fabricated DQPSK modulator module. The module size is 90×15×9.5 mm³, nearly equal to conventional intensity modulator module. Complementary I- and Q-electrical-signals are fed through four GPPPO connectors at one side. Monitor PD is settled in this module for bias control. DC bias ports for bias control are separate from signal ports.

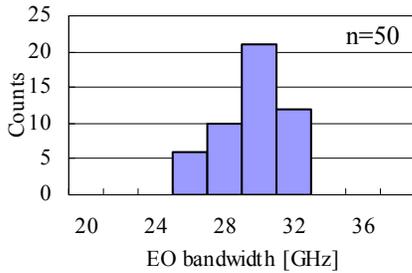


Fig.5 Histogram of EO bandwidth



Fig.6 Outer view of DQPSK modulator module

4. Conclusion

We have developed 40 Gb/s DQPSK LiNbO₃ modulator with low-drive-voltage of 3.5 V, high extinction ratio, and uniform EO response among four ports that enabled a precise mapping to DQPSK constellation at 43 Gb/s. We also confirmed good characteristics for 50 test module samples and high reliability. These results indicate that our DQPSK modulator is ready to practical use.

5. References

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