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A bias condition monitor technique for the nested Mach-Zehnder modulator

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Abstract: A nested Mach-Zehnder (MZ) modulator, which consists of two sub MZ interferometers embedded in a main MZ interferometer, is a multifunctional modulator. It can work as an optical single side-band (SSB) modulator, a differential quadrature phase shift keying (DQPSK) modulator and so on. Despite difficulties due to their complex structure, in order to avoid the operation instability of such modulators the bias condition of each MZ interferometer must be controlled automatically according to the modulation formats. In this paper, we proposed a specific bias condition monitor technique to the nested modulator.

Keywords: nested MZ modulator, bias control, monitoring

Classification: Photonics devices, circuits, and systems

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1 Introduction

Various advanced modulation formats, such as single side-band (SSB) [1], frequency shift keying (FSK) [2], differential quadrature phase shift keying (DQPSK) [3], etc, were investigated to obtain enhanced spectral efficiency or receiver sensitivity. In particular, DQPSK modulation method has drawn most attention for the 40 Gbps optical communication system because it is expected to be better-tolerated to polarization mode dispersion. A nested Mach-Zehnder (MZ) modulator, previously reported as an integrated $LiNbO_3$ (LN) versatile optical modulator consisting of two sub MZ interferometers with signal electrodes embedded in a main MZ interferometer [4], can generate optical signals in various modulation formats. This modulator can control the in-phase (I) and quadrature (Q) components of the output lightwave in each sub MZ interferometer, and is applicable for DQPSK modulation. In 40 Gbps DQPSK modulation, each sub MZ interferometer functions as a 20 Gsymbol DPSK modulator, therefore it doesn't require high-performance electrical circuits or additional equipment for polarization dispersion compensation in the optical transmission system.

A commercial LN modulator has intrinsic problems such as drift phenomena caused by the ambient temperature changes and the applied dc bias for setting the bias point appropriately. The bias depending drift phenomenon seems not to be completely eliminated because of the dielectric nature from which the LN modulator is comprised, even though the phenomenon has been physically understood and the production procedures have been improved [5]. Accordingly, the auto bias controller which can monitor and feed back the output bias condition to the modulator is necessary to drive the modulator stably in the long term. However, unlike in the case of the single MZ intensity modulator, it is difficult for each MZ part of the nested modulator to control the bias condition independently because our previously reported case has only one optical output port. Considered the practical use as a DQPSK or an SSB with suppressed carrier (SSB-SC) modulator, the sub MZ interferometers must be biased at null-bias points of the dc transmission curves and, at the same time, the main must be biased at a quadrature-bias point automatically and independently. In this paper, to provide a solution for this problem, we have proposed a specific bias condition monitor technique, and fabricated an integrated modulator with three monitor ports directly connected to two sub MZ and a main MZ interferometers. The output signal of the monitor port would be intensity inverted from the optical output port. Thus, by maximizing the intensity of the monitor ports, the sub MZ interferometer can be adjusted to be at a null-bias point which is an optimal condition for DQPSK or SSB-SC modulation.

2 Structure of the nested MZ modulator with bias condition monitor ports

The nested MZ modulator consists of parallel MZ modulators (MZ_A and MZ_B) integrated in a main MZ modulator as shown in Fig. 1 (a). For DQPSK

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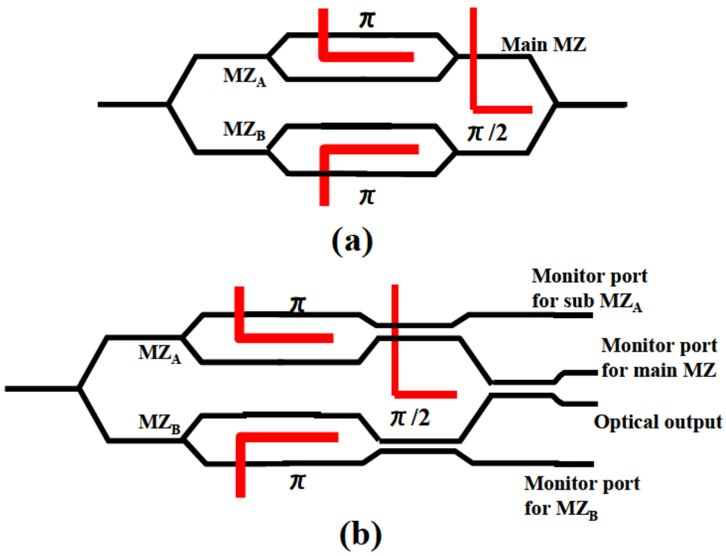

Fig. 1. Schematic diagram of the nested MZ modulator for DQPSK/SSB modulation: (a) basic structure, and (b) integrated structure with monitor ports

modulation, a pair of data signal is applied to the two sub MZ structures, to achieve control of I and Q components. Each sub MZ structure should be at a null-bias point, where the optical output intensity of each sub MZ goes to the minimum. Lightwaves in two arms of each sub MZ interferometer have π phase difference at the Y-junctions of the output port side, and would be converted into raditive modes. At the same time, the main MZ structure should be at a quadrature-bias point for the orthogonal combination of I with Q components, where lightwaves in two arms of the main MZ have $\pi/2$ phase difference. The same condition is equally true of SSB-SC modulation. To monitor bias condition of main and sub MZ structures, we propose an integrated modulator device as shown in Fig. 1 (b), where directional couplers were used as junctions of the sub and main MZ structures at the output port side. Each directional coupler has two output ports with same structure. In the sub MZ structure, one was connected to the Y-junction of the main MZ interferometer, and the other was used for monitor purpose. The main MZ structure also has two output ports, one for monitor and the other for the required signal output. The intensity profiles in the two output ports of each directional coupler would be inverted. In order to set the bias of the sub MZ structures at null points, which are optimal condition for DQPSK/SSB-SC modulation, the intensity of the monitor ports just have to be maximized. The waveguides were formed on the 1-mm-thick x-cut LN wafer by Ti diffusion at about 1000°C for 15 hrs, where the coupler parts were designed finely for the effective coupling. The 800-nm-thick SiO_2 buffer layer was deposited by rf magnetron sputtering of a SiO_2 target in Ar/O_2 mixture and then, annealed at 600°C for 5 hrs. Here, we employed an x-cut LN wafer in view of the simplicity of the experimental set-up and less thermal drift effect than the z-cut LN wafer. Upon the SiO_2 buffer layer, Au-electrode layers were electroplated in the sub and main MZ interferometers. Au-electrodes for two

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sub MZ and a main MZ structures were 3.2 cm and 1.1 cm long while the half wave voltage $V\pi$ were 4.1 V and 13.5 V, respectively. The excess loss at the optical out put port was 8.5 dB.

3 Bias condition monitor

We examined the optical monitor performance of the nested MZ modulator in the experimental set-up shown in Fig. 2 (a). By feeding a sinusoidal waveform signal to each MZ structure from a function generator, we measured the optical response of each monitor port output. Figure 2 (b) and (c) show the optical response of the monitor ports for the MZ_B and the main MZ, feeding 2.5 Vpp and 7.0 Vpp of 1 kHz sinusoidal waveform signals to each of them. It can be seen that the monitor outputs are ideally intensity inverted from the input electrical waveform or the optical signal output. The extinction ratio of the monitor output of the MZ_B and the main MZ were 37.5 dB and 20.1 dB. These results are good enough for monitoring the bias conditions precisely. With auto bias controllers that can feed back the monitored bias conditions to MZ structures, the nested MZ modulator can be applicable to practical optical communication systems.

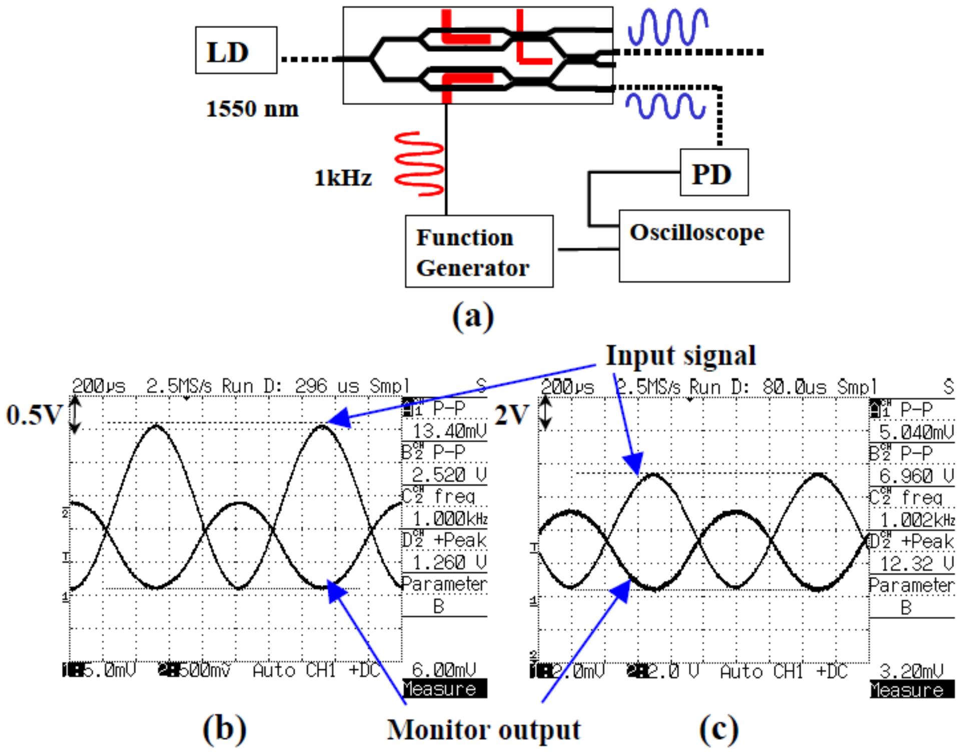

Fig. 2. Bias condition monitor: (a) experimental set-up, (b) response of monitor port of an MZ_B and (c) response of monitor port of a main MZ.

4 Conclusion

We proposed a nested MZ modulator in which directional couplers are inte-

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grated for bias condition monitoring. The bias condition of each MZ structure was successfully and independently monitored with high extinction ratio. The optical response of the monitor port was ideally intensity inverted from the input electrical waveform. Our fabricated modulator will be contributory to the commercialization of the 40 Gbps optical transmission system using DQPSK format.

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