Double-Pass PBS-Integrated Coherent Mixer Using Silica-based PLC

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Abstract: A coherent mixer with double-pass polarization-beam splitters integrated in silica-based PLC is newly developed. It is experimentally confirmed that the developed PLC-chip successfully works in the receiver for 40-Gbit/s dual-polarization quadrature phase-shift keying signal.

OCIS codes: (130.3120) Integrated optics devices; (060.1660) Coherent communications; (060.2330) Fiber optics communications.

1. Introduction

Dual-polarization quadrature phase-shift keying (DP-QPSK) combined with digital coherent detection schemes [1,2] is a promising modulation format to achieve ultra-high speed optical transmission over 40 Gbit/s/ch with a high spectral efficiency. To demodulate DP-QPSK signal, polarization-beam splitter (PBS) as well as coherent mixer (90-degree optical hybrid) are required in the receiver. Conventional free-space bulk optics might be useful for PBS and coherent mixer, but they tend to be large and not tolerant of a wide-range temperature change. On the other hand, silica-based planar lightwave circuit (PLC) can offer small-size and robust functional optical devices such as PBS [3,4] and coherent mixer [5]. Recently, a PLC-based coherent mixer with integrated PBS has been proposed [6], where passive optical functions to demodulate a dual-polarization coherent signal are performed in one chip. A PBS used in [6] consists of a single Mach-Zehnder interferometer (MZI), and realized the polarization extinction ratio over 25 dB. For better receiver performance, a PBS with double-pass structure [4] is desired to further improve the extinction ratio, and at the same time, the size of a PLC-chip should be kept small.

In this paper, we report at the first time a double-pass PBS-integrated coherent mixer employing silica-based PLC technology. As a result of double-pass PBS structure, a high polarization extinction ratio of 33 dB is achieved. Meanwhile, the size of fabricated chip is so small that 25mm x 21mm. Using the fabricated chip in the receiver, we conduct a transmission experiment of 40-Gbit/s DP-QPSK signal over 200-km SSMF, and verify that the developed PLC-chip successfully work as the front-end in the receiver for DP-QPSK signal.

2. Design and characteristics of developed PLC

Figure 1(a) shows a schematic diagram of newly developed PLC-chip of double-pass PBS integrated coherent mixer. The input signal propagates through a MZI-based PBS of the first stage, and the signal elements of the TE and TM polarizations are then split into different paths. The PBSs of the second stage improve the polarization extinction ratio of the TE/TM signals. We note that the folding layout of the PBSs and the following mixers contribute to downsizing the PLC-chip. Between the second PBS and the mixer for the TE-signal, a half-wave plate (HWP) with 45-degree inclined principal axis is inserted, and the signal polarization is then converted to the TM-mode. On the other hand, we assume that a continuous wave (CW) from a local oscillator (LO) has the TM polarization. The CW is simply split and guided to the mixers. Thus, the polarization-demultiplexed signals and the CW from the LO are injected into the upper and lower coherent mixers in the same polarization, that is the TM mode. After the coherent mixers, optically demodulated signals are given from the eight output ports. The output signals are then injected to balanced photo detectors (BPDs) through free space or fibers.

We fabricated a PLC-chip having the above design, and the picture is shown in Fig.1(b). The characteristics of the chip are also summarized in Table 1. The chip size was 25x21mm, which was so small in spite of the double-pass PBS structure. In Table 1, the maximum insertion loss and the minimum polarization extinction ratio of the eight output ports measured at the wavelength of 1552nm are shown. The insertion loss of the chip includes bonding, propagation, and connector loss of the fiber for measurement, but preclude the fundamental loss of 9 dB (LO input port) and 6 dB (Signal input port). The minimum polarization extinction ratio was 33.2 dB, which was so large thanks to the double-pass PBS structure. Finally, for evaluating the coherent mixers, we configured MZIs comprising an extra PLC-chip [6] and the chip under test. Note here that the extra chip has a splitter and a delay line, and the length of the delay line was adjusted in the design so that the free-spectral range (FSR) of the MZIs becomes 100 GHz. We then observed in the frequency domain the interference patterns of the MZIs as shown in Fig.2, and confirmed that the upper and lower mixers well operate as 90-degree optical hybrids.

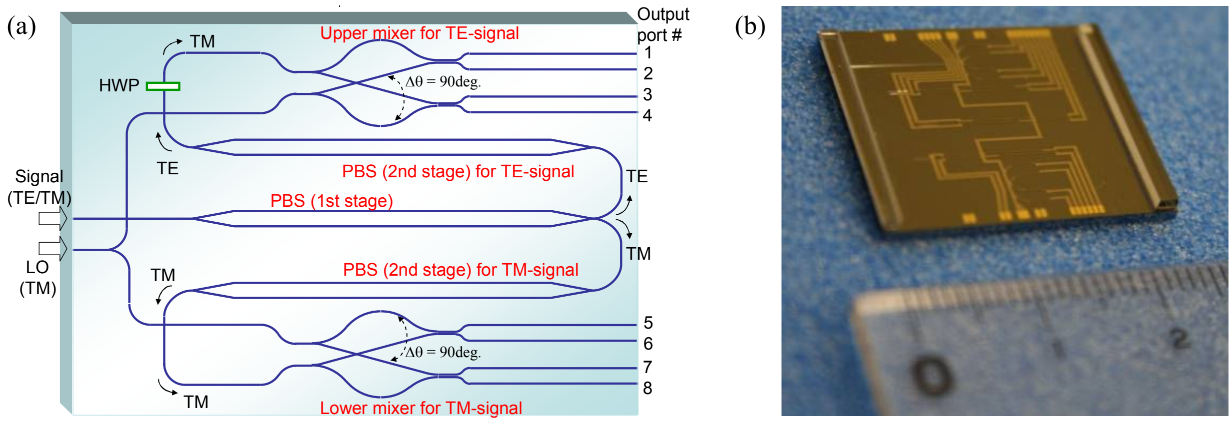

Figure 1. (a) Schematic diagram of proposed double-pass PBS-integrated coherent mixer based on PLC, and (b) picture of a fabricated PLC-chip.

Table 1. Characteristics of the fabricated PLC-chip.

Item	Value	Unit
Size	25x21	mm
Maximum excess loss from LO input port	2.6	dB
Maximum excess loss from signal input port	4.1	dB
Minimum polarization extinction ratio	33.2	dB

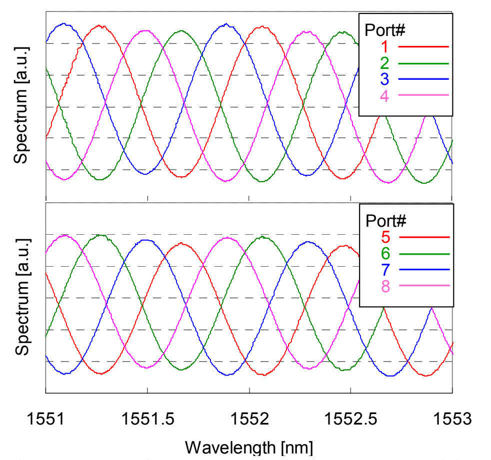

Figure 2. Interference patterns of MZIs comprising the integrated coherent mixers.

3. Transmission experiment

To evaluate the performance of the developed PLC-based coherent mixer as the front-end in the receiver for dual-polarization coherent signal, we conduct a transmission experiment of 40-Gbit/s DP-QPSK signal. Figure 3 represent the experimental setup, where fibers are used for the connection between the PLC-chip and the BPDs. The wavelength of the signal and the LO is 1552nm. We note here that a HWP is not used in the PLC as shown in Fig.1(a) for a simple experimental setup. Instead, we adjusted the polarization of the LO so that it has both the TE/TM polarizations with the same power.

Figure 4 represents constellation maps of demodulated signals at back-to-back and after 200-km transmission, obtained after the digital signal processing. As can be seen in Fig.4, the signals are well demodulated even after a long-distance unrepeatered transmission. Figure 5 shows the result of bit-error rate (BER) measurement for back-to-back and transmitted signals, which is equivalent to the result in the case of using free-space bulk-optics-based receiver. Hence, we have confirmed that the newly developed PLC-based coherent mixer with double-pass PBS works well in the receiver for 40-Gbit/s DP-QPSK signal transmission.

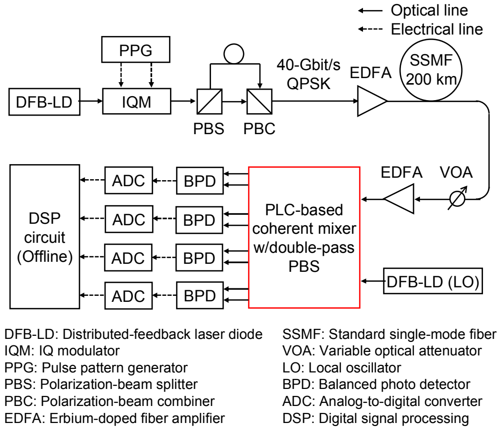

Figure 3. Setup for 40-Gbit/s DP-QPSK signal transmission experiment.

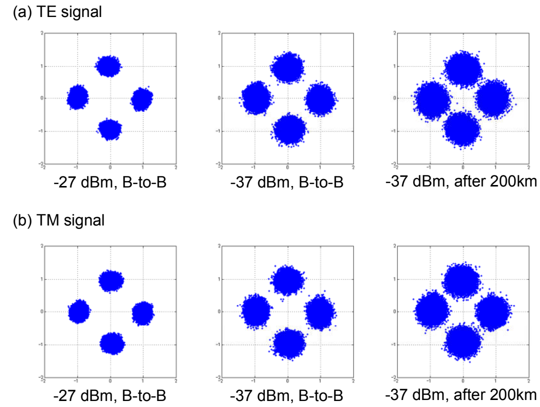

Figure 4. Constellation maps of back-to-back (B-to-B) and transmitted DP-QPSK signals.

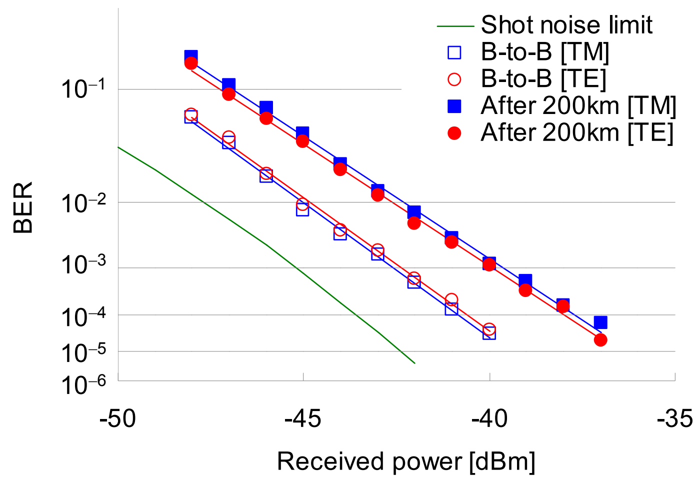

Figure 5. BER vs. received power for 40-Gbit/s DP-QPSK signals.

4. Conclusion

We have proposed a coherent mixer with double-pass PBS integrated in silica-based PLC. A compact-size PLC-chip with folding waveguide structure is designed and fabricated, and a large polarization extinction ratio of more than 33 dB is achieved thanks to the double-pass PBS structure. Applying the fabricated PLC-chip to transmission experiment of 40-Gbit/s DP-QPSK signal, we confirmed that the PLC-chip shows enough performance to demodulate the signal.

The authors thank K. Kikuchi, K. Igarashi, Y. Mori, and C. Zhang of Univ. Tokyo, for conducting the transmission experiment for this work.

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