One-chip Integrated Dual Polarization Optical Hybrid using Silica-based Planar Lightwave Circuit Technology

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Abstract *We demonstrate a compact dual polarization optical hybrid achieved by the integration of polarization beam splitters and 90°-hybrids using silica-based planar lightwave circuit. The fabricated device exhibited sufficient characteristics for coherent systems such as DP-QPSK.*

Introduction

Advanced modulation formats using coherent detection with digital signal processing (DSP) have been attracting considerable attention because of their high spectral efficiency, high receiver sensitivity and high resilience to the linear impairments such as chromatic dispersion and differential group delay[1, 2]. In particular, the dual polarization quadrature phase-shift keying (DP-QPSK) format has been extensively investigated with a view to achieving a 100-Gb/s channel rate in WDM systems[3]. A digital coherent receiver consists of optical front-end, analog-to-digital converters and a DSP unit. The optical front-end requires two polarization beam splitters (PBSs), two optical 90°-hybrids (OHs) and four sets of balanced photodiodes (PDs) to retrieve the amplitude and phase information of a polarization-multiplexed signal. Several approaches for the integration of above-mentioned components have been proposed to reduce receiver size and cost. For instance, the integration of single OH and two sets of balanced PDs based on InP technology have already been reported[4, 5]. Moreover, Doerr *et al*. demonstrated the monolithic silicon photonic integrated circuit with integrated germanium detectors[6]. On the other hand, the integration of PBSs and OHs using the silica-based planar lightwave circuit (PLC) technology was reported[7]. The silica-based PLC has such advantages as a lower insertion loss and field proven long-term reliability. In addition, there is a realistic possibility of the integration of PLC and OE devices[8].

This presentation reports one-chip integrated dual polarization optical hybrid (DPOH), which consists of two PBSs and two OHs, using silica-based PLC technology. By comparison with the primary report[7], further improvements in compactness, insertion loss, phase accuracy and polarization extinction ratio were achieved by employing a new waveguide design and a phase tuning technique. We report experimental results showing that silica-waveguide DPOHs exhibit satisfactory characteristics as coherent receiver components.

Design

Figure 1(a) shows the schematic configuration of our proposed DPOH. The signal and local oscillator (LO) lights are launched into respective PBSs and separated into the transverse electric (TE) and transverse magnetic (TM) modes. Then, the signal and LO components enter the OH for each polarization state. To monitor the phase difference between the outputs from the DPOHs during tuning process, we installed a 1×2 coupler and a delay line so that the circuit as a whole consists two sets of 1×4 delay interferometers. After the phase difference tuning, we cut out unnecessary part (shown by the gray line in Fig. 1(a)) in front of the PBSs.

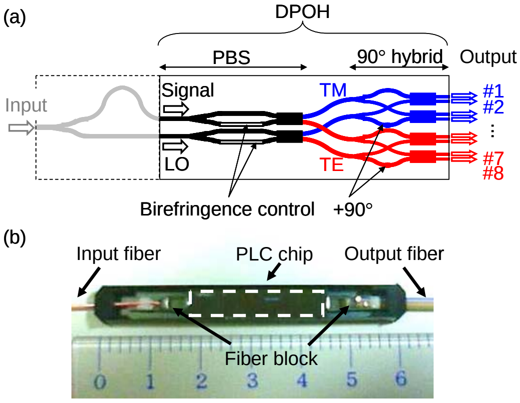

Fig. 1. (a) Schematic configuration of DPOH
(b) Photograph of fabricated module

Next, we describe the design of the PBS and OH. The PBS is composed of a 1×2 coupler, two waveguide arms and a 2×2 multimode interference (MMI) coupler. The waveguide birefringence of one arm is adjusted so that the path length difference between the two arms for the TE mode differs by half a wavelength compared with that for the TM mode[9]. We controlled the birefringence by introducing stress release grooves along the waveguide core. The OH consists of two 1×2 couplers, four waveguide arms and two 2×2 MMIs. We made one arm a quarter wavelength longer than the other arms to give a phase difference of 90° between the in-phase and quadrature (I and Q) channels.

Experimental Results

We fabricated the DPOH by using silica-based PLC technology. The refractive index difference was 1.5% and the waveguide core was 4.5 μm thick. The output waveguides were separated by 250 μm at the output

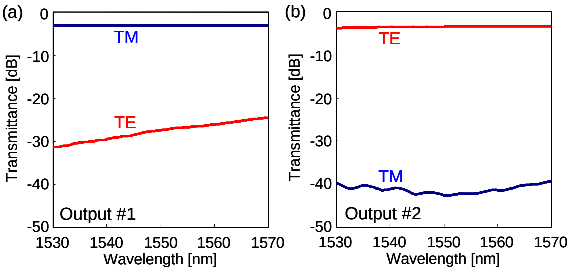

Fig. 2. Transmittance spectra of PBS for two outputs

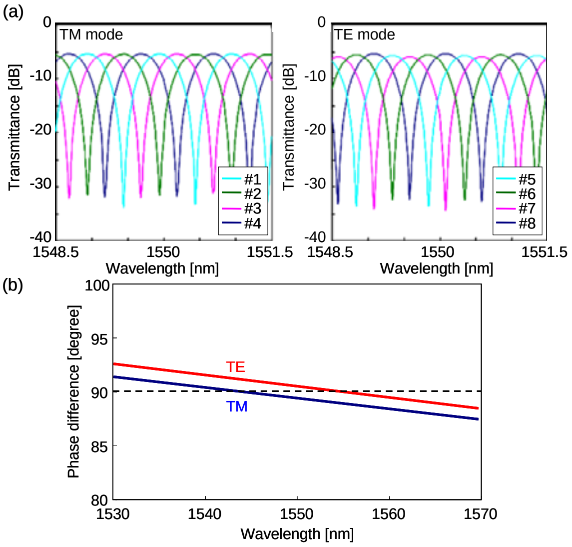

Fig. 3. (a) Transmittance spectra of DPOH with delay line
(b) Phase difference between I and Q channels

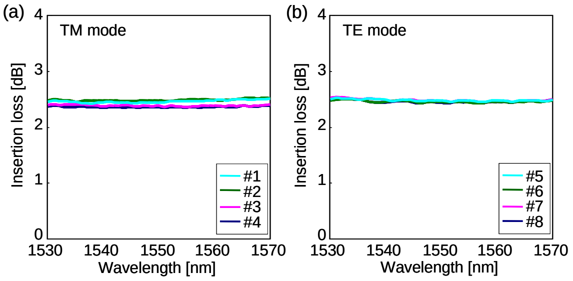

Fig. 4. Insertion losses: (a) outputs #1-4 (b) outputs #5-8

facet. After tuning the phase difference and cutting out the unnecessary part, the fabricated chip was attached to optical fibers and packaged as shown Fig. 1(b). The PLC chip size and package size was 28×5, 62×6×3.5 mm, respectively.

We estimated the PBS characteristics accurately by measuring samples consisting solely of PBSs fabricated on the same wafer. Figure 2 shows the measured transmittance spectra for two outputs. The fabricated PBS had polarization extinction ratios of >25 dB over the C-band for both outputs. It is possible to obtain a higher polarization extinction ratio and a wider bandwidth by optimizing the design parameters.

We investigated the phase differences between the outputs by measuring the transmittance spectra of the delay interferometers during tuning process. The phase differences were precisely adjusted by tuning the refractive index of the OH arms with UV laser irradiation[10]. Figure 3(a) shows the measured transmittance spectra after the phase difference adjustment. Figure 3(b) shows the phase differences between the I and Q channels for both polarization states evaluated from the spectra. The phase deviations from 90° were less than 3° over the C-band. The phase differences adjusted with UV laser irradiation are permanent. Thus, our DPOH works completely passively in practical use.

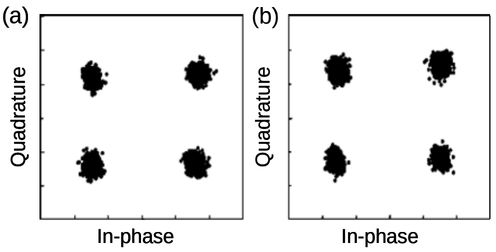

Fig. 5. Measured constellation for one polarization state
(a) silica-waveguide DPOH
(b) commercially avaiable DPOH (free-space optics)

Figure 4 shows the measured insertion losses from the signal port to the outputs. The intrinsic loss of 6 dB is not counted in Fig. 4. The insertion losses were less than 2.5 dB and the loss variations between all the outputs were less than 0.2 dB across the C-band. Moreover, we confirmed that the differences between the insertion losses from the signal and LO ports were less than 0.2 dB for all the outputs.

Figure 5 (a) and (b) show constellations for a 20-Gbaud QPSK signal, which were received with our DPOH and commercially available DPOH based on free-space optics, respectively. Our DPOH showed the comparable performance to that of a commercially available free-space optics one. We also successfully received a 64-level quadrature amplitude modulated (QAM) signal with our DPOH, in a demonstration of a new PLC-LN integrated modulator[11].

Conclusion

We demonstrate a one-chip integrated fully passive DPOH using silica-based PLC technology. The fabricated device was very compact, and its characteristics were sufficient for coherent detection over the C-band. We believe that silica-waveguide DPOHs will contribute greatly to providing compact and cost-effective optical front-end for coherent detection receivers.

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