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TR2013-069 July 2013

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The Optical Society (OSA)

A Low-loss Integrated Beam Combiner based on Polarization Multiplexing

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Abstract: We present a design of an integrated beam combiner which cascades power combiners and polarization converter/combiner. The proposed device has 2 dB lower loss than power combiners and is more fabrication-tolerant than wavelength combiners.

OCIS codes: (230.3120) Integrated optics devices; (230.5440) Polarization-selective devices

1. Introduction

Optical beam combiners are essential components in wavelength-division multiplexed (WDM) systems. There are typically two types of optical beam combiners, i.e., power combiners and wavelength combiners. Multimode interference (MMI) based couplers are commonly used as power combiners for combining multiple optical signals with different wavelengths. However, the power loss is relatively high in such devices. For example, a 4×1 MMI coupler can combine four optical signals, while the power loss is at least 6 dB for each signal [1]. Examples of wavelength combiners include arrayed-waveguide gratings (AWGs), ring-resonator filters [3], and photonic bandgap material based filters [4]. Wavelength combiners are typically narrow-band, which can cause signal distortion. Although wavelength combiners theoretically provide low power loss, it requires in practice a precise control of fabrication and small errors in the dimensions of the combiner can lead to a large insertion loss [2].

Polarization multiplexing is typically not used in optical data communications applications such as 4-wavelength 40/100 Gb/s Ethernet [5], where each wavelength consists of a single polarization. Optical sources such as lasers typically oscillate in the same transverse electric (TE) polarization. However, there is typically no requirement for relative polarizations among optical signals. Optical signals in a single mode fiber can be in any polarization. It is thus worthwhile to explore the possibility to utilize both polarizations in optical device design.

In this paper, we show that novel optical beam combiners can be designed by taking advantage of polarization multiplexing. The design cascades power combiners or wavelength combiners in conjunction with polarization converter/combiner. With this cascaded approach, a 4×1 optical beam combiner based on indium phosphide (InP) to operate at around 1301 nm is designed and simulated. The device has an insertion loss below 4.03 dB, which is a significant improvement over conventional power combiners, for all four wavelengths.

2. Operating principles

We design optical beam combiners using a two-stage approach to cascade conventional power combiners or wavelength combiners with polarization converter/combiners. The use of polarization converter/combiner reduces insertion loss and increases bandwidth, making the device superior to conventional power combiners and wavelength combiners.

Fig. 1 shows a block diagram of a 4×1 optical beam combiner with the two-stage design approach. The four input signals are in TE mode with different wavelengths, labeled TE^1, TE^2, TE^3, and TE^4. In the first stage, two 2×1 power combiners are used without changing the polarization of signals. TE^1 and TE^2 are combined by power combiner 1, and TE^3 and TE^4 are combined by power combiner 2. In the second stage, signals TE^1 and TE^2 are converted to TM modes, labeled TM^1 and TM^2; polarization of TE^3 and TE^4 is preserved and combined with TM^1 and TM^2 through a polarization combiner.

While various options are available for both power combiners and polarization converter/combiners designs, we use MMI-based 2×1 power combiners for simplicity, and a recently proposed structure [6] for polarization conversion and combination. It has been shown that such a mode-evolution based device is low-loss, wide-band, and fabrication tolerant [6]. Although the device was proposed as a polarization converter/splitter, it can be used reversely as a polarization converter/combiner, as shown in Fig. 2.

The polarization converter/combiner consists of four sections. The first section is an adiabatic asymmetric Y-coupler, which accepts incoming optical signals in fundamental TE_0 mode in its two branches. At the end of the Y-coupler, the TE_0 mode signals of the upper branch are converted to second order TE_1 modes; the mode of lower branch signals is maintained. The second section is a width taper, which converts second order TE_1 mode signals into fundamental TM_0 mode signals through a low-loss and highly-efficient adiabatic process. TE_0 signals propagate through the width taper without changing polarization. The third section is a bi-level taper, which converts any remaining TE_1 signals into TM_0 signals. The fourth section is a width taper to eliminate higher order modes. Eventually signals from upper branch of the device is converted to TM_0 signals, and signals from lower branch go through the device in TE_0 polarization.

3. Device design & simulation

Based on the above design principles, a 4×1 optical combiner is designed based on epitaxial-grown structure with InP substrate. The core layer of the structure is indium gallium arsenide phosphide (InGaAsP) of 300 nm thick, with a composition 60% lattice matched to InP. Cladding is another InP layer of 140 nm thick. The device structure is shown in Fig. 3. The width of input waveguide is 2 μm for all four wavelengths; width of the MMI power combiner is 5 μm each. The Y-coupler in the polarization converter/combiner has a length of 400 μm, and widths of two branches of 1.1 μm and 2.1 μm, respectively. The width of the adiabatic taper changes from 3.3 μm to 2 μm over a length of 900 μm. The overall length of the device is about 1700 μm. The four TE_0 mode optical signals are fed into the device from four different ports in order from top to bottom, with wavelengths of 1295.56 nm, 1300.05 nm, 1304.58 nm, and 1309.14 nm, respectively [5].

The designed device is simulated using commercial software FIMMPROP [7]. Fig. 4 shows simulated field distribution of the four signals propagating through the device. As expected, in the first stage TE^1 combines with TE^2 signal through the upper MMI power combiner, which is then directed to the upper branch of the polarization converter/combiner; TE^3 combines with TE^4 signal through the lower MMI power combiner, which is then directed to the lower branch of the polarization converter/combiner. At the second stage, signals in the upper branch of the polarization converter/combiner undergo mode conversion from TE_0 to TE_1, and from TE_1 to TM_0; signals in the lower branch maintain the TE_0 polarization. Four signals are combined at the same output port. The calculated insertion loss is 3.98 dB, 4.03 dB, 3.56 dB, and 3.57 dB, respectively for the four wavelengths. Compared with conventional MMI power combiners, which have intrinsic loss of at least 6 dB, the proposed device has at least 2 dB power gain for each wavelength.

Note that various designs can be realized with this cascaded approach. For example, 2×1 wavelength combiners can be used in the first stage instead of power combiners. For this case, insertion loss of the combiner can be further reduced. Compared with 4×1 wavelength combiners, the cascaded design allows 2 times larger wavelength spacing by using polarization multiplexing, which leads to higher fabrication tolerance. It is also worth to mention that the design concept can be readily applied to material systems other than InP/InGaAsP, such as Silicon on Insulator (SOI).

4. Conclusions

In summary, a new approach of designing optical beam combiners based on polarization multiplexing was proposed. A 4×1 beam combiner, which cascades power combiners with polarization converter/combiners, was designed and simulated. The device was shown to have 2 dB lower loss compared with conventional MMI power combiners, yet more fabrication tolerant compared with wavelength combiners based on AWGs and ring resonators.

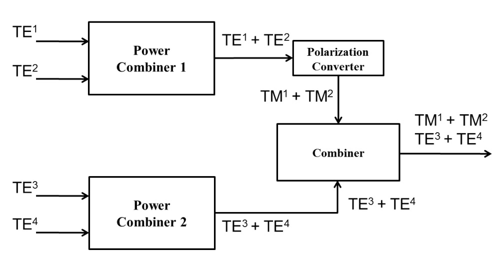

Fig. 1. Block diagram of a 4×1 optical combiner with a two-stage design approach.

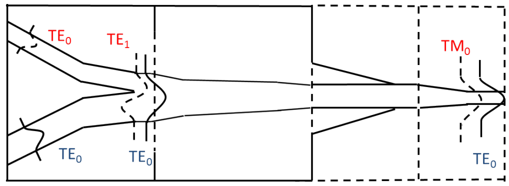

Fig. 2. A mode-evolution based polarization converter/combiner.

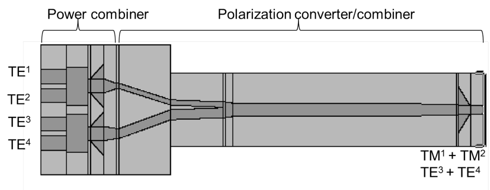

Fig. 3. Device structure of a 4×1 optical combiner used for simulation.

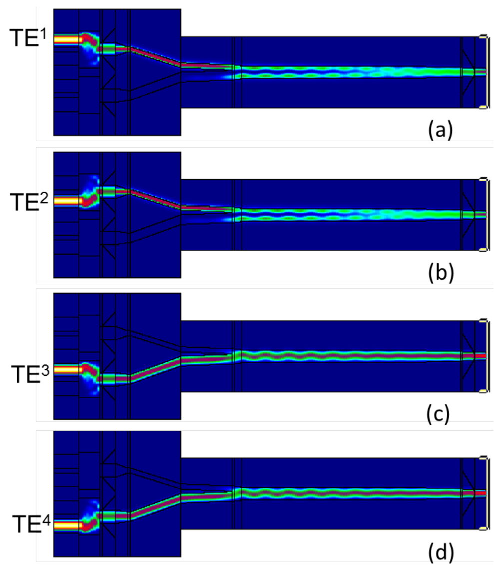

Fig. 4. Simulated field distribution in the 4×1 optical combiner for four input wavelengths (a) 1295.56 nm (b) 300.05 nm, (c) 1304.58 nm, and (d) 1309.14 nm.

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