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TR2012-038 September 2012

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Europearn Conference and Exhibition on Optical Communications

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Abstract *A novel polarization splitter on an InP substrate utilizing an MMI coupler with a patterned gold layer and a tilted joint is proposed. The MMI section is less than 540 μm. Simulations show that the device has a polarization extinction ratio over 23 dB and an insertion loss below 0.7 dB over the entire C-band for both TE and TM polarizations.*

Introduction

Polarization splitters are key components for high-speed optical communication networks, both for polarization-diversity and polarization-division multiplexing (PDM) applications [1]. A polarization splitter built on an Indium Phosphide (InP) substrate is especially of interest due to its capability of integration with active components [2].

A Multimode Interference (MMI) coupler is an excellent building block for polarization splitters due to its compactness, large bandwidth, and high fabrication tolerance. However, it is very difficult to design an MMI-based polarization splitter on InP for two reasons: MMI couplers are inherently polarization-insensitive, and strong polarization birefringence is difficult to achieve in InP material systems due to small index contrast between core and cladding layers compared to Silicon-On-Insulator (SOI) systems. As a result of the weak polarization birefringence, a long device length, e.g. several millimeters long [3], is required for the MMI-based polarization splitters to separate TE and TM modes. Different methods such as the quasi-state MMI coupler [4] and the slot waveguide [5] have been proposed to reduce the total device length. However, none of these methods can reduce the device length without compromising the device performance or inducing extra fabrication difficulties.

In this article, we propose a novel design of a polarization splitter utilizing a 1-by-2 MMI coupler. By incorporating a phase shift section featured by a metal-dielectric cladding layer [6] and a tilted joint [7] into the MMI-based polarization splitter, a strong polarization birefringence between TE and TM modes is created, resulting in very strong separation of TE and TM modes at the output waveguides.

Design

The function block diagram of the device is shown in Fig. 1. The input signal (TM or TE), coupled into the 1×2 MMI, is split into two arms with equal phase and equal power. The phase shift section is designed to add an extra –π/2 phase shift to the TM mode in the upper arm and an extra –π/2 phase shift to the TE mode in the lower arm. When the electric fields from both arms are combined via the 2×2 MMI coupler, the electric field in one output coming from the cross arm has an extra –π/2 phase shift compared with that from the bar arm. The interference between electric fields with different phases causes the TM polarization mode to appear at the upper output whereas the TE polarization mode appears at the lower output. The phase shift section with the function described above is achieved by using a tilted MMI coupler partially covered by a gold layer on a SiN_x layer as shown in Fig. 2 (a). In this design, the phase

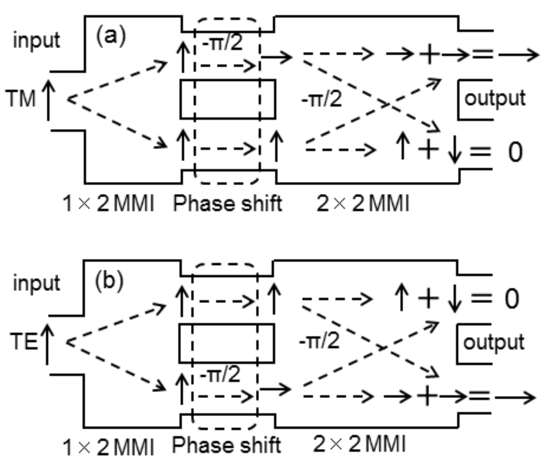

Fig. 1: Function block diagram of polarization splitter based on MMI couplers. The arrows indicate the phases of the electric field.

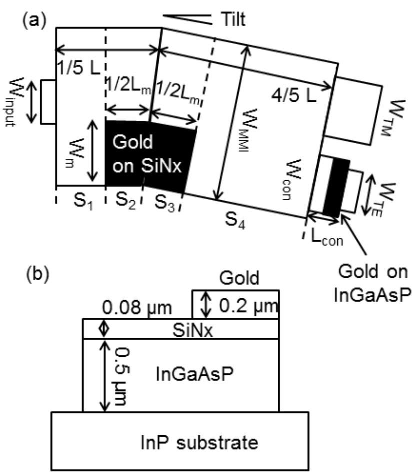

Fig. 2: (a) The schematic top view of the proposed MMI-based polarization splitter and (b) the cross section view of the phase shift section (S_2 and S_3) with metal-dielectric cladding layer.

shift section (S_2 and S_3) is integrated into the 1×2 MMI and 2×2 MMI coupler, which helps to reduce the total device length. The partial gold layer in the phase shift section tends to push the electric field of TE mode away from it, which reduces the propagation constant for TE mode, and to pull the electric field of TM mode toward it, which increases the propagation constant for TE mode. These opposite effects add an extra -θ–π/2 phase shift to the TM mode in the upper arm or an extra θ–π/2 phase shift to the TE mode in the lower arm. The constant phase, θ, can be set to 0 by adjusting the tilt angle.

The geometrical parameters of the design are described as follows: the input waveguide has a width of W_{input}=4.5 μm. The MMI section is composed of four sections, S_1, S_2, S_3, and S_4. The S_1 and S_4 sections do not contain the deposited gold layer, whereas the lower parts of the S_2 and S_3 sections are covered by deposited gold. The S_2 and S_3 sections are joined by an angled tilt of 0.45 degree. The MMI section has a width of W_{MMI}=10 μm and a total length of L=538 μm. The metal (gold) layer has a width of W_m=4.5 μm and a length of L_m=72 μm in total. The lengths of the S_1, S_2, S_3, and S_4 sections are 1/5L-1/2L_m, 1/2L_m, 1/2L_m, and 4/5L-1/2L_m, respectively. The upper output has a width of W_{TM}=4.5 μm and is placed 3 μm from the center of the MMI coupler. The first section of the lower output has a width of W_{con}=4.9 μm and a length of L_{con}=47 μm; the second section of the lower output has a width of W_{TE}=4.45 μm. The device is built on InP substrate with a 0.5 μm thick InGaAsP (λ=1.3 μm) layer as waveguide core, and 0.08μm thick Silicon Nitride (SiN_x) layer as buffer layer. The gold layer is 0.2 μm thick. The cross section view of the phase shift section is shown in Fig. 2 (b). A 10 μm-long polarizer, where gold layer is directly deposited on InGaAsP is also included in the lower output waveguide, to absorb residual TM mode, while TE mode is passed with minimal loss.

Simulations

The performance of the polarization splitter is simulated using commercial software Fimmwave employing the eigenmode expansion method [8]. The finite element mode solver is used for solving modes in all sections. Fig. 3 shows the interference patterns of the MMI-based polarization splitter excited by (a) fundamental TM mode (TM_0) and (b) fundamental (TE_0) mode inputs. For better illustration, the tilted MMI coupler is mapped into a straight waveguide. As predicted, the single self-images for TM and TE modes build constructively near the upper and lower outputs, respectively. However, the self-image plane for TM polarization, Z_{TM}, does not coincide with the self-image plane for TE polarization, Z_{TE}. When the upper and lower outputs are placed at the TM self-image plane, accurate TE self-image cannot be obtained at the lower output, which reduces the transmission. To solve this problem, a two-section TE output waveguide is designed. As shown in Fig. 3 (b), the first section of the lower output waveguide functions as a mode converter, refocusing the divergent electric field

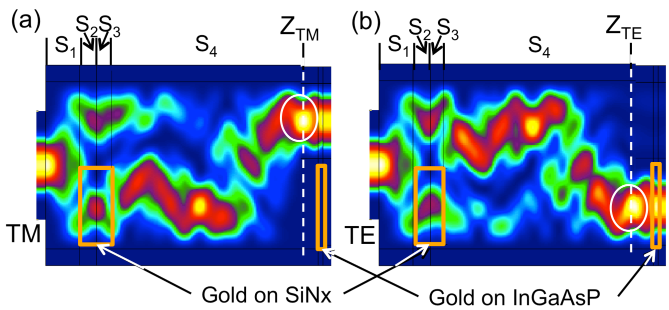

Fig. 3: The electric field intensity in the MMI-based polarization splitter showing the wave propagation for (a) TM_0 mode and (b) TE_0 mode inputs.

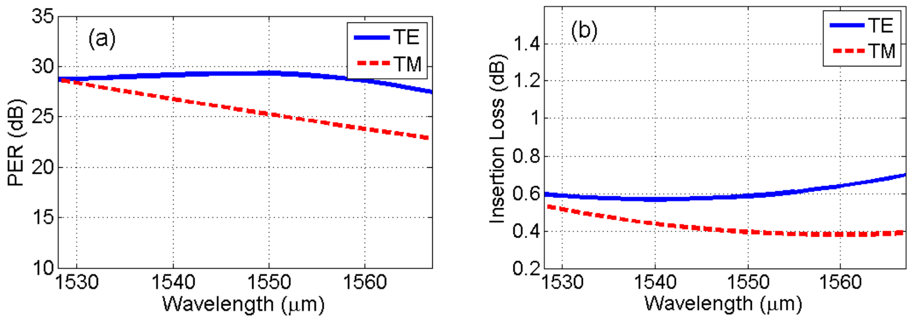

Fig. 4: (a) PER and (b) Insertion loss for TE_0 and TM_0 modes as a function of wavelength.

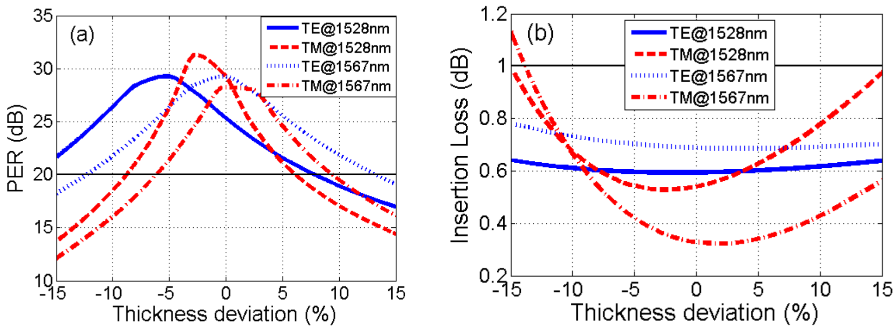

Fig. 5: (a) PER and (b) Insertion loss for TE_0 and TM_0 modes as a function of SiN_x layer thickness error.

of the TE_0 mode back into a self-image.

Fig. 4 shows the polarization extinction ratio (PER) and insertion loss for TE_0 and TM_0 modes as functions of wavelength from 1528 to 1567 nm, covering the entire C band. For both TE and TM polarizations, the polarization splitter of this design exhibits an insertion loss smaller than 0.7 dB and PER larger than 23 dB over the wavelength range of 39 nm.

The fabrication tolerance is also studied in this work. In device fabrication, the most sensitive parameter is the SiN_x buffer layer thickness, which controls the phase shift. Fig. 5 shows the PER and insertion loss of TE_0 and TM_0 modes at the wavelength of 1528 nm and 1567nm, as functions of thickness error of SiN_x buffer layer. For both TE and TM polarizations, the polarization splitter of this design exhibits an insertion loss smaller than 1 dB and PER larger than 20 dB with the thickness variation of +/- 6.2%.

Conclusions

A novel MMI-based polarization splitter on an InP substrate is proposed. By integrating a metal-dielectric cladding layer in combination with a tilted joint into the MMI section, a strong polarization birefringence is created, resulting in separation of TE and TM modes within a short propagation distance. The total device length is less than 600 μm, which is much shorter than the device of length 1050 μm with similar MMI section width reported in [4]. Simulation shows that the device has a PER greater than 23 dB and an insertion loss below 0.7 dB over the wavelength range from 1528 to 1567 nm for both TE and TM polarizations. The fabrication tolerance is also studied, showing that for a thickness variation of +/- 6.2% the insertion loss remains below 1 dB and the PER remains over 20 dB. Although this device is proposed for InGaAsP/InP material systems, it could also be readily employed for other material systems.

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