Integrated magneto-optic Mach-Zehnder interferometer isolator for TE-modes

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Abstract

A concept for an integrated optical Mach-Zehnder interferometer isolator for TE-modes is presented. Vertically magnetized magneto-optic rib waveguides with a compensation wall serve as nonreciprocal phase shifters for the fundamental TE-mode. The nonreciprocal phase shifts in both interferometer arms add as the jumps of the Faraday rotation at the compensation walls have opposite sign.

1 Introduction

For the development of integrated optical circuits it is desirable to have optical isolators for TE-modes as well as for TM-modes. Different concepts for TM-mode isolators based on nonreciprocal Mach-Zehnder interferometry have been proposed in the past [1, 2, 3, 4]. They rely on the nonreciprocal phase shift of the fundamental TM-mode in lateral magnetized garnet rib waveguides [5]. The nonreciprocal phase shift of TE-modes in vertically magnetized rib waveguides with a magnetic domain lattice [6] or with a compensation wall [7] has been predicted recently. The latter ones form the central part of the proposed Mach-Zehnder interferometer type isolator.

2 Device Structure

A schematic illustration of the nonreciprocal Mach-Zehnder interferometer is shown in fig. 1. In a nearly compensated magnetic garnet film of composition $Y_3Fe_{5-x}Ga_xO_{12}$ with $x \approx 1.3$ the sign of the Faraday rotation can be changed in a rectangular area by a special annealing process [8]. After masking the desired part with a Si layer, the process redistributes the Ga content on the octahedral and tetrahedral sites of the garnet. This leads to a change of the sign of the Faraday rotation at room temperature. The boundary is designated as a compensation wall. Thereafter the interferometer is structured such that the compensation walls define the symmetry axes of the central waveguides (see fig. 2). Since the Faraday rotation switches in one arm from positive to negative and in the other arm vice versa, the nonreciprocal phase shifts add. For a proper performance of the device the interferometer arms must be in phase in the forward direction. In the backward direction a phase difference of π is required. If each nonreciprocal arm induces a nonreciprocal phase shift of $\pi/2$, in one arm an additional reciprocal phase shift of $\pi/2$

is necessary. This is achieved by a local change of the propagation constant as a result of modified waveguide parameters, e. g. a reduced film thickness. The same procedure is utilized for the required tuning of the intrinsic phase [4]. An outstanding feature of the proposed isolator is that the nonreciprocal parts of the isolator are well-defined. They are limited by the annealed rectangle. Since the refractive indices are not affected by the annealing, there will be no reflections in the interferometer.

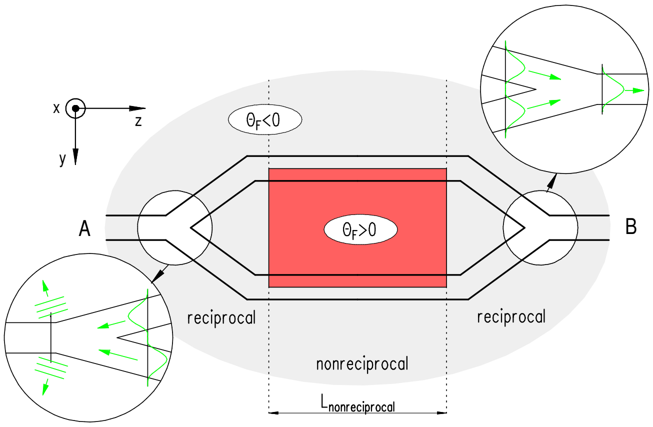

Figure 1: Top view of the proposed Mach-Zehnder interferometer. A special annealing process changes the sign of the Faraday rotation in the central region which leads to compensation walls in both waveguides.

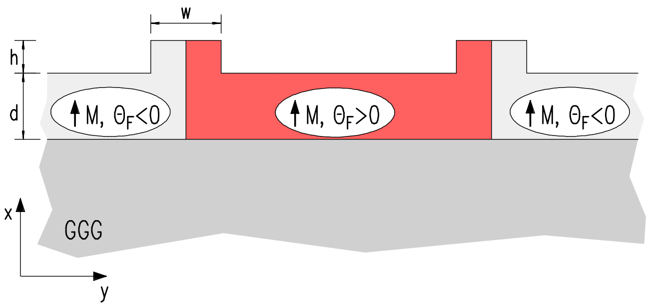

Figure 2: Cross-section of the Mach-Zehnder interferometer. The central region, with positive Faraday rotation ($\Theta_F > 0$), is separated from the outer parts with negative Faraday rotation ($\Theta_F < 0$) by two compensation walls.

3 Simulations

The nonreciprocal phase shift $\Delta\beta$ of the proposed waveguides is calculated with a finite element method [7]. For typical waveguide parameters ($n_{\text{substrate}} = 1.9, n_{\text{film}} = 2.2, \Theta_F = \pm 3000^\circ/\text{cm}$) the results are plotted in fig. 3. Using the maximal value of $\Delta\beta$ for each curve, the minimum required length of the nonreciprocal phase shifters $L_{\text{nonreciprocal}} = \pi/2\Delta\beta$ can be estimated to be 991 μm, 692 μm and 479 μm for the rib heights 0.1 μm, 0.2 μm and 0.5 μm, respectively.

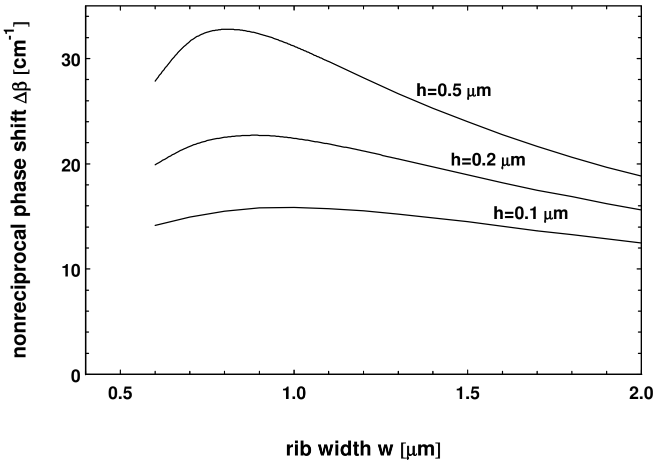

Figure 3: Calculated nonreciprocal phase shift $\Delta\beta$ of the fundamental TE-mode versus the rib width. The film thickness is $d = 0.3$ μm, $\lambda = 1.3$ μm.

4 Conclusion

This paper presents a novel design for an integrated optical isolator for the fundamental TE-mode. A special annealing technique must be applied to produce two compensation walls with an opposite jump of the Faraday rotation. If these walls are located in the center of the interferometer arms, one obtains two well-defined nonreciprocal phase shifters the nonreciprocal phase shifts of which add. The estimated arm lengths are comparable to those of TM-mode isolators with two oppositely magnetized double layer phase shifters of equal Faraday rotation.

Acknowledgements

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