High Isolation Optical Isolator: A new Building Block for PolyBoard Photonic Integrated Circuits

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Abstract *We experimentally demonstrate a polymer-based optical isolator, hybridly integrating two GRIN lenses and a Faraday Rotator. An isolation of 20 dB over a bandwidth of 80 nm was achieved, with a peak isolation of 33 dB.*

Introduction

Optical isolators are one of the key components in optical data transmission systems, as they prevent unwanted back reflections and thus assure stable laser operation. So far, commercially available optical isolators rely on bulk free-space solutions, which have to be externally integrated into the package of a laser source, increasing the package size and incurring additional assembly costs[1]. In photonic integrated circuits (PICs), optical isolators are still in the development phase and different proposals can be found in literature. Some of the most relevant devices rely on Mach-Zehnder-Interferometer (MZI) or micro-ring-resonator (MRR)-based structures, combined with bonded magneto-optical materials on the waveguides[2,3,4]. However, both approaches suffer from high intrinsic losses due to the bonding process, and require tuning of the structure in order to optimize the isolation properties.

In this work, we present an optical isolator in HHI's polymer-based hybrid integration platform PolyBoard[5]. Using two graded-index (GRIN) lenses, we create an on-chip free-space collimated beam section, which allows for the insertion of an external magneto-optic material to implement a Faraday rotator (FR) and a half-wave plate (HWP). This method provides a strong interaction of the propagating optical beam and the magneto-optical material, which enables for a 45° Faraday rotation on a small footprint (485 µm). Together with polarization beam splitters (PBSs), they form a compact optical isolator for integrated optics.

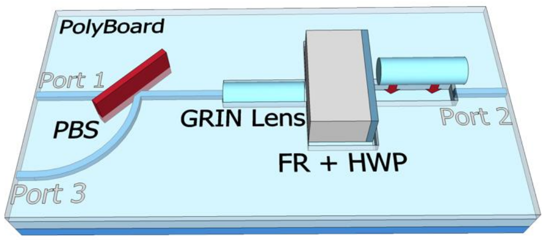

Fig. 1: Schematic layout of the optical isolator, consisting of polymer waveguides, an inserted polarizing beam splitter (PBS) and a on-chip free-space region created by two GRIN lenses to integrate a bulk Faraday rotator and a half wave plate.

Operation principle

The schematic layout of the isolator is shown in Fig. 1. The device consists of two input ports (port 1 and port 3), for TE or TM polarized light, respectively, which are combined via the PBS. The PBS transmits TE polarized light and reflects TM polarized light with low insertion losses (~0.5 dB) and a high polarization extinction ratio (25 dB)[5], resulting in TE transmission from port 1 to port 2 and TM transmission from port 3 to port 2. The Faraday rotator inserted in the free-space section formed between the GRIN lenses creates a non-reciprocal 45° polarization rotation. In combination with the HWP (slow axis set to 22.5° with respect to the TE polarization), this results in polarization conservation in forward direction, and a 90° polarization rotation in backward direction. Fig. 2a shows the general working

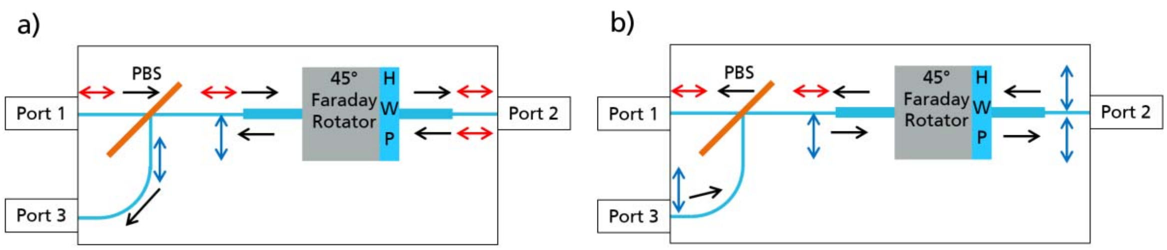

Fig. 2: Working principle of the optical isolator for TE polarization (red horizontal arrows) from Port 1 (a) and TM polarization (blue vertical arrows) from Port 3 (b).

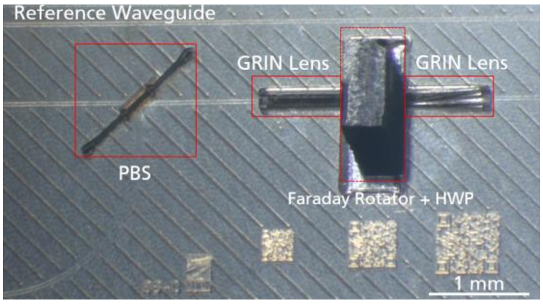

Fig. 3: Fabricated optical isolator with highlighted integrated micro optical elements.

principle of the optical isolator for TE polarization, resulting in optical isolation for port 1, and TM polarization (Fig. 2b) which results in optical isolation for port 3. As it can be inferred from Fig. 2, the device also acts as an optical circulator, propagating the TE-polarized light from port 1 to port 2, and from port 2 to port 3. Similarly, TM-polarized light will be routed from port 2 to port 3, and from port 3 to port 1

Design and fabrication

The fabricated device is shown in Fig. 3. It consists of buried polymer waveguides with a quadratic cross section of 3.2 µm x 3.2 µm, and a refractive index difference between core and cladding of 0.03.

To create an on-chip free-space section, we use a pair of GRIN lenses with a pitch of 0.25, a length of ~870 µm and a diameter of 125 µm. The lenses are integrated via pre-etched U-grooves, which allow for passive alignment and integration into the PIC.[6] The first GRIN lens collimates the incoming beam of the polymer waveguide, creating a collimated beam at the GRIN lens output. After a free-space section, the second GRIN lens focuses the light back into the waveguide. A pre-magnetized Bismuth-doped YIG crystal with a thickness of ~485 µm acts as the 45° Faraday rotator, which can be placed directly into the free-space section without the need of an externally applied magnetic field. We use commercially available Faraday rotators with a Faraday rotation tolerance of <±0.5° and an antireflective coating on both facets, which are diced into smaller pieces to fit into the designed slots. Additionally, a polyimide 22.5° half-wave plate is glued to the output facet of the FR. The thin-film filter acting as PBS is placed directly into an etched slot. Both filters do not require additional GRIN lenses to compensate for the beam divergence of the waveguide/free-space interface due to their small thicknesses of ~15 µm

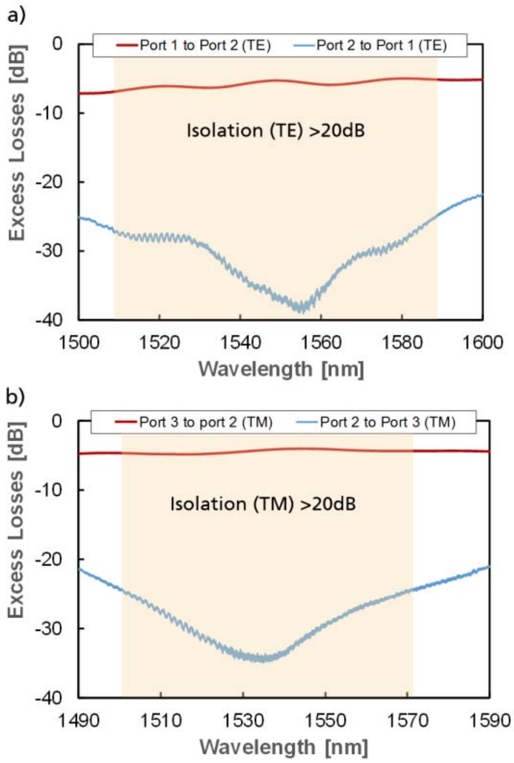

Fig. 4: On-chip transmission in forward and backward direction of the fabricated optical isolator, for TE polarization (a) and TM polarization (b).

and 12.6 µm, respectively.

Results

In order to characterize the fabricated device, measurements with TE and TM polarized light were conducted for both input ports 1 and 3. Fig. 4 shows the excess losses in the path between port 1 and 2 (for TE-polarized light) and in the path between port 3 and 2 (for TM-polarized light), for both backward and forward directions. From Fig. 4, the calculated isolation from port 1 to port 2 is >20 dB over a bandwidth of 80 nm with a peak isolation of >33 dB for TE polarization. The isolation from port 3 to port 2 is >20 dB over 70 nm. The peak isolation ratio is >30 dB for TM polarization. The on chip losses in forward direction are at 5.3 dB for port 1 to port 2 and 4.1 dB for port 3 to port 2 at a wavelength of 1550 nm. The reason of the higher excess losses for the TE input (port 1) with respect to the TM input (Port 3) is the longer free-space propagation length through the PBS in transmission[7]. The on-chip losses of 4 dB can be attributed to the coupling losses between waveguide and GRIN lens, the beam divergence of the Gaussian beam in the free-space section and small misalignments in the assembly process. For optimal alignment, simulations show that the coupling losses of the free-space section can be improved by 3 dB.

The shift of the isolation ratio peak for the TM polarization to lower wavelengths and the lower optical isolation ratio with respect to the TE polarization can be attributed to an angular misalignment of the Faraday rotator and half wave plate during the assembly. This could be overcome with automated mounting of the different on-chip elements, which is currently under development.

Outlook

The hybrid integration approach of external micro-optical elements allows for easy upscaling of device complexity without large obstacles in fabrication yield. By introducing a second PBS right after the GRIN lens free-space section (concept not shown here), we can obtain polarization-independent optical isolation. Furthermore, the addition of a second free-space section with a Faraday rotator results in a polarization-independent isolator for both forward and backward direction, which also works as a polarization-independent optical circulator, circulating the light from port 1 → port 2 → port 3. The proposed structure for this optical isolator/circulator is depicted in Fig. 5.

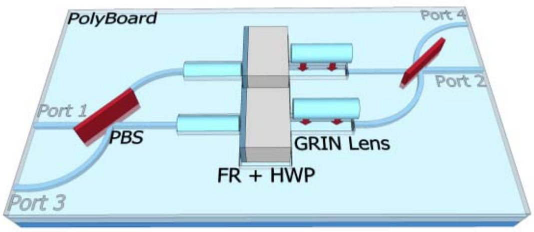

Fig. 5: Proposed structure for a polarization-independent optical circulator/isolator (under investigation).

Conclusions

In conclusion, we demonstrated a polymer-based integrated optical isolator by implementing an on-chip free-space section, which enables the hybrid integration of an external Faraday rotator. With an isolation ratio of 20 dB over a bandwidth of 80 nm and a peak isolation ratio of 33 dB, we showed the capabilities of high isolation, as well as broadband isolation. Based on the polarization-dependent isolator demonstrated, we propose the design for a polarization-independent isolator and circulator. These elements are novel building blocks in the PolyBoard photonic integration platform, and can be combined with tunable lasers and other readily available active and passive functionalities in PICs. Besides isolation/circulation, the free-space beam section allows for a multitude of non-data-transmission applications in emerging fields such as the integration of nonlinear crystals for quantum optics.[8]

Acknowledgements

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