Towards on-chip polarization management and isolation in O- and C-band integrated silicon photonics

L. Bogaert,[1,3] J. Zhang,[1,3] P. Ossieur,[2,3] and G. Roelkens[1,3]

[1] Photonics Research Group, INTEC, Ghent University - imec, 9052 Ghent, Belgium
[2] IDLab, INTEC, Ghent University - imec, 9052 Ghent, Belgium
[3] Center for Nano- and Biophotonics, Ghent University - imec, Ghent, Belgium

In this paper we describe our work towards on-chip isolation and polarization management for 220 nm silicon photonic integrated circuits. In the first part, we will focus on the addition of non-reciprocal functionalities through the use of micro-transfer printing of magneto-optic films such as Ce:YIG. Such an on-chip isolator will be key to improve the stability and hence the overall performance of on-chip lasers. While these on-chip lasers typically emit TE mode light, on-chip isolator circuits are preferable operating in TM mode. Consequently, we have designed polarization rotators working at 1550 nm with a simulated TE0-to-TM0 conversion efficiency of 98.5%. The envisioned heterogeneously integrated optical isolator relies on a silicon-on-insulator (SOI) Mach-Zehnder interferometer (MZI), with a transfer-printed Ce:YIG film coupon on top of the MZI arms. Its simulated non-reciprocal phase shift is about 1.3 rad/mm. Secondly, we have been working towards an O-band on-chip polarization tracker including a polarization rotator-splitter (PRS) and a monitor feedback loop that is capable of translating an arbitrary input polarization state to a linearly polarized TE mode at the output. Initial measurements on this PRS component show obvious sensitivity to dimensional variations and should be further investigated.

Introduction

Photonic integrated circuits (PICs) that are implemented using silicon photonics (SiPh) based platforms benefit from the well-established CMOS electronic integrated circuit industry. These benefits include low-cost, high-volume manufacturing and high-yield fabrication. Additionally, due to the high index contrast between silicon and its oxide, SOI platforms enable the realization of high complexity PICs in compact footprints.

Currently, one of the main markets where SiPh is being deployed is in transceivers. Because of the growing need for very high speed data delivery, even between chips, optical interconnects are favored over electrical links already at very short distances. Furthermore, optical I/O directly from the chip would allow for optical switching, with the potential to greatly reduce latency and power consumption of the overall system, thereby providing a future-proof solution for high-performance computing.

When co-integrating laser(s) in the transceiver, performance, in terms of stability and noise level, can degrade substantially in case of reflections. To make the link more robust, an optical isolator should be added at the laser output. Non-reciprocal functionalities can be added through the micro-transfer printing (MTP) of magneto-optic materials. Therefore, the next two sections will cover MTP and the envisioned C-band isolator. Another useful building block for e.g. optical switching is a polarization tracker. This device can linearly polarize an arbitrary input polarization state. Since PICs are highly polarization dependent, interconnecting them often requires polarization controllers or dual-polarization circuits with digital signal processing (DSP). In the final part of this paper, we will discuss how such a polarization tracker can be implemented.

Micro-transfer printing

Commercial SiPh platforms have matured significantly over the past years and already contain an extensive library of passive and active components at the telecom wavelengths. This includes structures for fiber coupling, on-chip routing, passive signal processing, high-speed modulation and detection, etc. However, some of the functionalities that are desirable to implement fully integrated systems on SiPh chips are not natively available. Hybrid and heterogeneous integration can tackle this problem and enable more complex photonic integrated circuits. Both flip-chip integration and wafer bonding are mature integration techniques, however, the former is inherently low-throughput and high-cost while the latter requires substantial modifications to the well-established SiPh back-end process flow. Micro-transfer printing, depicted in Fig. 1, has been proposed as a solution that can be adopted for wafer-scale massively parallel integration of non-native devices on a SiPh target [1]. It decouples the processing of the devices from the SiPh process flow and makes efficient use of non-native material. Furthermore, it allows to integrate a whole variety of different components on a single SiPh wafer. An overview of this technique, together with several demonstrators implemented in our group, is described in [1].

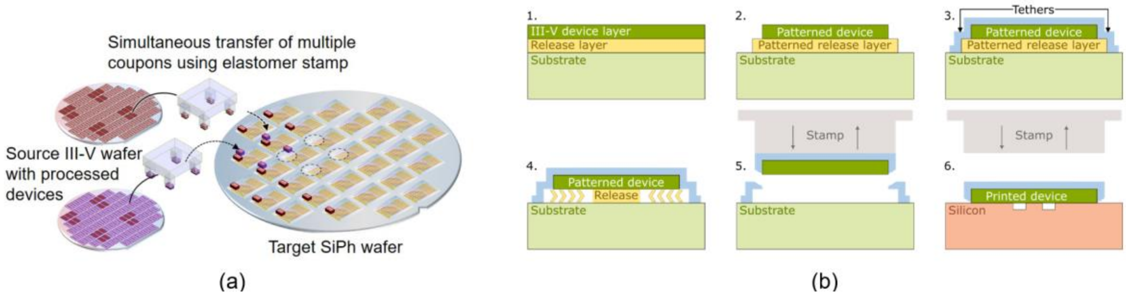

Fig. 1 (a) Wafer-scale heterogeneous integration of III-V devices on a SiPh wafer through MTP; (b) Process steps include definition, release and printing – both images are reproduced from [1]

C-band on-chip isolator

MTP-enablement allows for integrated lasers to be included in SiPh PICs but these devices potentially suffer from high back-reflections causing significant deterioration of the stability and hence overall performance of the on-chip laser. Performance can be boosted by also including isolators on-chip, however, this requires the inclusion of magneto-optic material films in the platform. In [2], it has been shown that this non-reciprocal functionality can be added to SiPh based platforms through MTP a Ce:YIG film on top of a SOI MZI. In the presence of an external magnetic field they were able to construct an on-chip isolator with an isolation ratio of 14 dB [2].

We are working on a similar demonstrator on imec's iSiPP200 SiPh platform with the post-printing stack described in Fig. 2(a). The target SOI wafer includes an MZI with 220 nm thick Si waveguides. Before printing the magneto-optic film, a thin layer of benzocyclobutene (BCB) is deposited to serve as an adhesive agent to achieve high quality bonding and for high yield. The envisioned coupon consists of 50 nm YIG and 100 nm Ce:YIG, the latter with a Faraday Rotation Coefficient (FRC) of -3500 deg/cm at 1550 nm. The non-reciprocal phase shift (NRPS) is inversely proportional to the required device length and should therefore be as large as possible [3]. CAMFR simulations were performed on a slab approximation [3] of the stack, and the results are depicted in Fig. 2(b). The intermediate oxide and BCB thickness should be minimized to achieve maximal NRPS, while a top Si_3N_4 cladding can help to pull the mode more into the Ce:YIG and thereby enhance the NRPS. For the aforementioned stack with 30 nm thick BCB, 600 nm thick Si_3N_4 and in the absence of intermediate SiO_2 the simulated NRPS is approximately 1.3 rad/mm. The resulting total coupon length is 1208 μm, or equivalently 604 μm per MZI arm, to offer the π/4 NRPS per arm that is required for broadband isolation when using a unidirectional magnetic field [3]. This isolator operation, similar to [2], relies on

TM polarized light while on-chip lasers often output TE. As a solution, we designed an on-chip polarization rotator that is described in Fig. 2(d) and comprises two parts. The first part converts TE0 to TE1, and is based on the 6-section design from [4], while the second part introduces TE1 to TM0 conversion. This part is implemented as a bilinear taper to reduce its footprint. TE-to-TM conversion is enabled by creating vertical asymmetry through the use of top air cladding in the entire polarization rotator, as illustrated in Fig. 2(c). This component shows a simulated polarization rotation efficiency of 98.5% and is currently being fabricated for characterization.

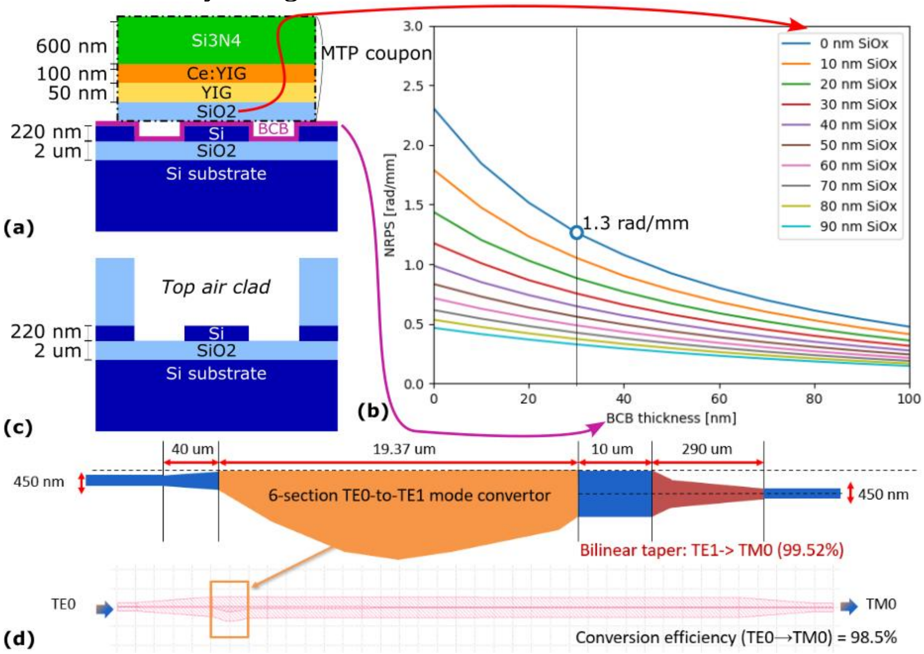

Fig. 2 (a) Isolator stack with MTP magneto-optic coupon on SOI; (b) Simulated NRPS for slab version of stack (a); (c) Polarization rotator stack; (d) Polarization rotator design.

O-band on-chip polarization tracker

Polarization trackers (PTs) can play a crucial role in PICs that use edge coupler fed inputs. With these trackers, any arbitrary polarization state can be converted to a linearly polarized TE mode that can be processed in the next part of the chip. In particular in single-polarization coherent receivers, this means that we can have a reduced-complexity circuit where the local oscillator on-chip laser is mixed with the linearly polarized PT output. This avoids the need for processing two orthogonal polarizations of the input signal and reduces DSP complexity. The architecture of such a fully integrated coherent receiver is depicted in Fig. 3(a) and relies on a polarization tracker which is described in more detail in Fig. 3(b) comprising a polarization rotator and splitter (PRS) and a monitor feedback loop, where the output current of the photodetector is minimized by co-optimizing the drive signal of the 2 heaters [5]. The same polarization tracker can e.g. be used in optical switches. The PRS design, shown in Fig. 3(c), is an O-band (1310 nm) version of the design from [6]. FDTD simulations were performed on this component using Lumerical and it was found that for a TE input, the signal has only 0.003 dB loss towards the through port and -37.6 dB crosstalk at the coupled port. Meanwhile a TM input is rotated to a TE output with 0.15 dB loss at the coupled port and -20.87 dB crosstalk at the through port. A limited sweep of these devices was tested, and it was found that the designs are very sensitive to dimensional variations. This was verified with Lumerical in combination with a focused ion beam (FIB) cross-section of the fabricated directional coupler, where Lumerical indicated that even a 5 nm increase in through waveguide width already shifts the operation wavelength with +20 nm. In the fabricated device sweep, we noticed that a 40 nm excess through waveguide width suggests potential operation around 1340 nm. Since these devices are not working at the correct wavelength (1310 nm), the PT hasn't been tested, and a new sweep of PRS dimensions has been sent for fabrication. An alternative solution for the PRS with adiabatic coupling has also been taped out for improved robustness to fabrication but at the cost of a much longer device.

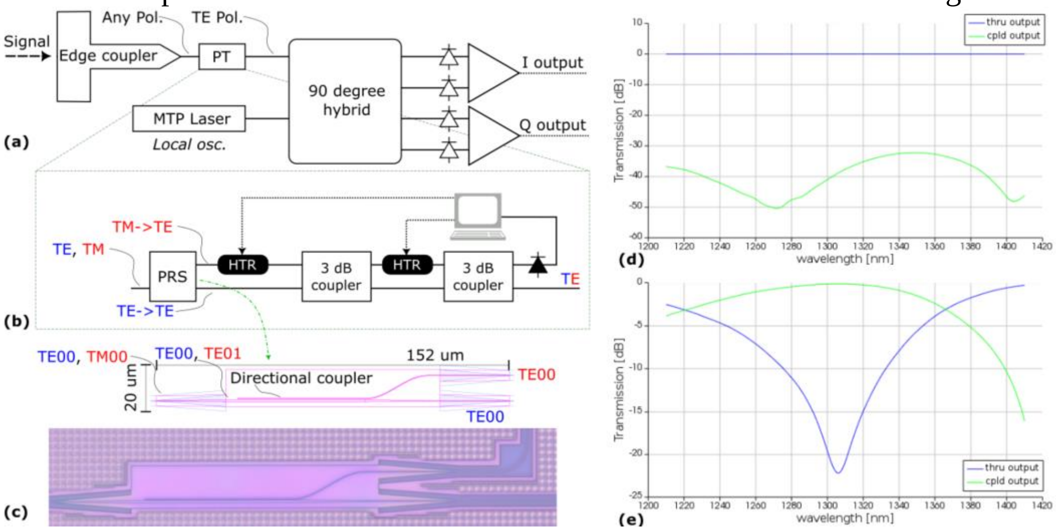

Fig. 3 (a) Fully integrated on-chip single-polarization coherent receiver; (b) Polarization tracker; (c) Polarization rotator & splitter; (d)/(e) Simulated transmission from TE/TM polarized input to both outputs.

Conclusion

Progress towards on-chip isolation and polarization tracking has been discussed in this paper. The on-chip isolator requires MTP of thin magneto-optic films on the SiPh platform. With the currently envisioned stack, an NRPS of 1.3 rad/mm is expected at 1550 nm. Furthermore, we worked on a C-band polarization rotator, with simulated conversion efficiency of 98.5%, to eventually connect this isolator to on-chip lasers. Meanwhile, a first batch of polarization tracking devices has been fabricated and measured. However, because of the great sensitivity of the PRS to its dimensions, it does not operate at the desired wavelength. A second generation of these devices has been taped out recently to assess the effects of dimensional variations more accurately.

Acknowledgements

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