Polarization-Insensitive Isolators and Circulators on InP Photonics

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Abstract: On-chip isolators and circulators are regarded as the last piece of puzzle for photonic integrated circuits. In this paper recent successful demonstration of a polarization insensitive design, compatible with the InP laser process on a thin membrane, is presented. © 2023 The Authors

1. Introduction

Semiconductor lasers are indispensable devices in communication and sensing systems, however they are naturally sensitive to external optical feedback [1]. The management of optical feedback to the lasers becomes even more challenging when complex photonic integrated circuits (PICs) are being built [2, 3], as light passes many more numbers of abrupt interfaces in those circuits. Although the development of feedback-tolerant lasers can mitigate the issue to a certain degree (e.g., up to a certain feedback level [4]), a general-purpose optical isolator/circulator, integrated on the chip, is of great interest to the community. The optical isolators block light propagating in one direction, while allowing light from the opposite direction to pass [5]. A circulator, built on optical isolators, can enable large-scale routing of the light within the complex circuits.

Several approaches exist to realize on-chip isolators and circulators. The most widely developed approach is based on integration of magneto-optic (MO) materials (such as Ce:YIG) on waveguide circuits. Comparing to nonlinear effects or spatiotemporal modulation based nonreciprocity, the MO effect itself is intrinsically linear and broadband. Based on the same MO material and similar working principle, the MO-based isolator/circulator can achieve performance comparable to the commercial fiber-coupled optical isolators [6]. However in many applications involving light scattering or polarization multiplexing, one may expect back-reflection or back-scattering with a different polarization state than that of the original source. A polarization insensitive optical isolator/circulator is essential for those applications, but was not available.

In this paper, a recently developed isolator/circulator architecture using integrated MO materials [7] is reviewed. The device is based on an InP membrane photonics platform, which offers native amplifiers and lasers on nanophotonic waveguides [8, 9]. The nanophotonic waveguides enables not only direct interaction of light with MO materials, but also ultracompact polarization controllers which are key to the first-reported polarization insensitive operation of the on-chip isolator/circulator. Realized on the InP nanophotonic circuits, the potential to be directly integrated next to the lasers, with a single process flow, will be discussed.

2. Isolator/circulator Architecture

The architecture of the isolator/circulator concept is shown in Fig. 1. In this design, two multimode interference (MMI) couplers are cascaded to form a Mach–Zehnder interferometer (MZI). A millimeter-sized die containing Ce:YIG film, sputtered on a SGGG substrate, is bonded onto the two parallel arms of the MZI, using ultrathin adhesive bonding [7]. According to the design, a non-reciprocal phase shift (NRPS) will occur in the transverse magnetic (TM) mode in the waveguide interacting with the Ce:YIG material. A π NRPS can be achieved with approximately 4 mm long waveguide/Ce:YIG interaction length based on current integration scheme. In one of the MZI arms (upper arm as shown in Fig. 1), two polarization converters (PCs) are implemented at the either sides of the Ce:YIG die. Their function is to rotate the input polarization by 90° (e.g., input TE mode converts to TM, and vice versa). This ensures that only one of the MZI arms contains light with TM polarization which experiences the NRPS (when the Ce:YIG die is biased with an in-plane magnetic field), while the other arm with TE polarization does not accumulate NPRS. In the other MZI arm, two cascaded PCs are used to maintain a balance of the losses. At the wavelengths where two arms are out of phase, a through-port transmission (e.g., port 1 to port 2) is realized. At the same time, backward reciprocity will not be achieved because backward-propagated light experiences the NRPS with an opposite sign, leading to an in-phase interference of the two MZI arms and output at cross-port (e.g., port 2 to port 3). Therefore isolation and circulation can be realized based on this principle [10]. Polarization insensitivity is ensured by the inserted PCs so that for either TE or TM polarization at the input, exactly the same through-port and cross-port transmissions will take place for forward and backward light, respectively.

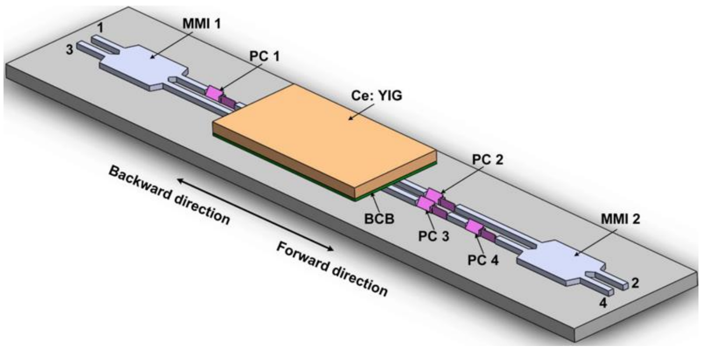

Fig. 1. Schematic illustration of the isolator/circulator architecture [7].

Although the first demonstration suffers from high insertion loss (> 30 dB), the overall performance in port-to-port isolations is promising: 18.6 dB – 27 dB for TE light and 16.4 – 34 dB for TM light [7, 10]. A detailed loss factor analysis shows that a route to single-digit insertion loss is feasible [10].

3. Key Enabling InP Membrane Platform

This polarization-insensitive isolator/circulator is realized on an InP membrane platform, which allows for closest integration of the demonstrated isolator/circulator with native lasers. A schematic illustration of the technology platform is depicted in Fig. 2. As can be seen, the semiconductor optical amplifier (SOA) in the InP membrane is based on a twin-guide scheme, where the active multiple quantum well (MQW) core couples with the passive i-InP waveguide evanescently. The membrane is double-side processed so that key optical structures are created before bonding, leaving a flat membrane surface after bonding. This is highly suited for further processing or heterogeneous integration with new functions such as the Ce:YIG die in this work and/or the SiO_2 based grating antennas.

The triangle-shaped polarization rotator is the key enabling element for the polarization-insensitive isolator/circulator. A PC, composed of two polarization rotator sections, is illustrated in Fig. 3. It is uniquely compact and efficient (~97.5 % TE/TM conversion efficiency for a 4 μm long device), exploiting very large modal birefringence existing in such asymmetric waveguides [11] (for mode profiles see insets in Fig. 3). A microheater, featuring state-of-the-art power efficiency and footprint [12], can also be integrated in the same platform. Such device can be used to fine tune the optical delays in the MZI to achieve a broad optical bandwidth [10]. It is also worth noting that both the microheaters and the polarization rotators share the same n-doped conductive layers with the SOA. This simplifies the layer stack design as well as the process flow significantly.

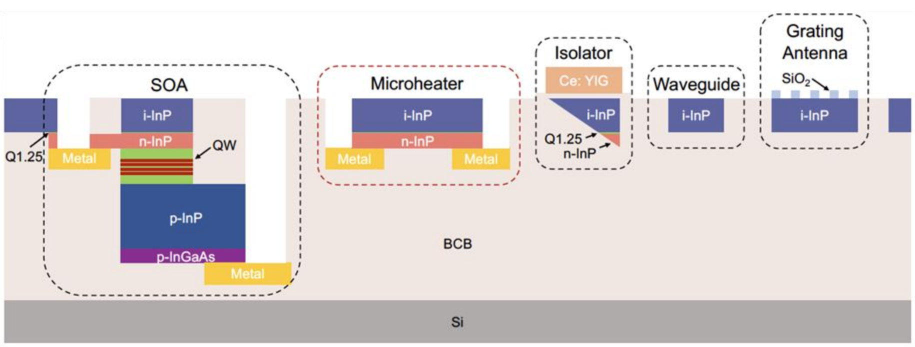

Fig. 2. Schematic illustration of the InP membrane integration platform [12].

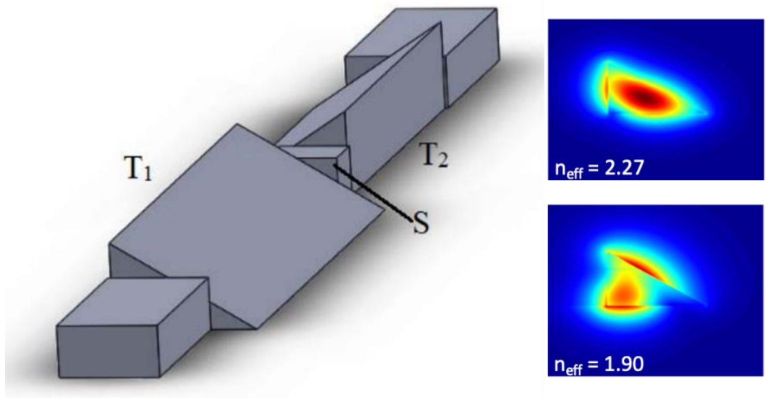

Fig. 3. Schematic of the PC composed of two polarization rotator sections [11]. Insets are the mode profiles and effective indices of the two eigen modes in the triangle waveguide.

4. Conclusion

In this paper, a novel architecture for on-chip polarization-insensitive isolator and circulator is discussed. The technology platform on an InP membrane is a key enabler to this demonstration. The platform not only features native amplifiers and lasers, but also provides the polarization rotators which are key to the polarization insensitivity of the isolator/circulator concept, as well as microheaters which can be used to further improve the optical bandwidth of the circuit. The demonstration shows the feasibility that a high-performance isolator/circulator can be realized on InP photonics and integrated right next to InP lasers.

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