ECIO 2016
18TH EUROPEAN CONFERENCE ON INTEGRATED OPTICS 2016
18–20 MAY | WARSAW | POLAND

Optical Isolators for Photonic Integrated Circuits

Martijn J. R. HECK
Aarhus University, Department of Engineering, Finlandsgade 22, 8200 Aarhus, Denmark
mheck@eng.au.dk

With the advance of mature fabrication technologies, photonic integrated circuits (PICs) reach ever-higher levels of complexity. Integration of thousands of components has been shown [1], with each main technology showing an exponential growth in complexity [2]. This increase in complexity requires a convergence in technologies, and the roadmaps are currently being pushed by silicon nitride, (hybrid) silicon and indium phosphide PIC technologies. This trend is further fuelled by the establishment of PIC foundries for these main PIC technologies.

Although this convergence on a few main PIC platforms and process flows is a requirement for increasing the complexity, yield, uniformity and robustness of PICs, and decreasing the cost, this means that flexibility on the physical level is limited. The emphasis shifts towards the circuit level. Practically this means that challenges for the application need to be solved by clever PIC design, instead of merging new materials or process steps into the fabrication flow.

One major challenge is the isolation between the various optical components on a PIC. Optical isolators are ubiquitously used in fiber-optic and discrete-optics systems, e.g., to prevent optical feedback from entering a laser cavity. Even minute amounts of coherent feedback, e.g., due to reflections further downstream the system, will increase the laser noise [3]. In silicon and silicon nitride PIC platforms the light source is hybridly integrated in the package, and discrete isolators can be added [4]. However, the indium phosphide and hybrid silicon platforms [5] do not have this option, as the laser is integrated on the PIC. Previous research has clearly shown the limitations due to on-chip optical feedback for tunable lasers [6], mode-locked lasers [7] and wavelength converters [8]. Although by careful design the on-chip reflections can be minimized [9,10], optical isolators with an isolation ratio of around -20 dB are still required.

Efforts to integrate practical optical isolators on a PIC typically include the use of magneto-optic (MO) materials, heterogeneously integrated onto the PIC. With these materials a nonreciprocal absorption [11] or phase shift [12] can be achieved. However, such MO materials are not part of the current PIC foundry platforms. Approaches that are compatible with existing foundry platforms typically make use of time-dependent index or amplitude modulation [13,14].

I will present and discuss two recent approaches to realize PIC foundry-compatible optical isolators. The first is based on hybrid integration of two PICs, using vertical grating couplers for coupling (Fig. 1) [15]. The second approach is based on the timed drive of a pair of optical modulators, with a main application in microwave photonics (Fig. 2) [16].

Partial funding from Det Frie Forskningsråd through the mmW-SPRAWL project (DFF – 4005-00246) is acknowledged.

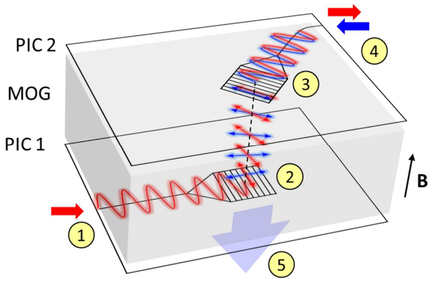

Fig. 3. Magneto-optic garnet (MOG) between two PICs. TE input light (1, red) propagates through first vertical grating coupler (GC, 2), MOG and second GC (3) to output (4). Counter-propagating TE light (blue) does not couple to the input (1), and is radiated out of the plane (5). The magnetic field direction is indicated by B. Picture from [15].

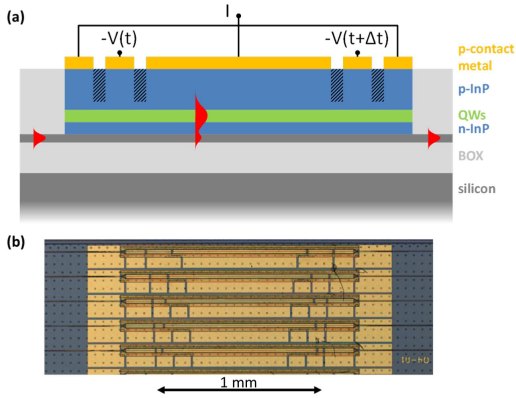

Fig. 4. (a) Hybrid silicon microwave-photonic isolator, showing the optical field (red). Time dependent reverse bias voltage V(t) modulates transmission. (b) Microscope picture of an array of realized devices. Pictures from [16].

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