Efficient Polarization Independent Optical Link in Bonded InP-membrane

Frederik Van Laere, Tiziana Stomeo, Dries Van Thourhout, Thomas F. Krauss, Roel Baets

Supervisor(s): Roel Baets, Dries Van Thourhout

Abstract **We report on an efficient optical link in bonded InP-membranes consisting of fiber grating couplers, waveguides and integrated photodetectors. By using a polarization diversity configuration this link can be made polarization independent.**

Keywords **Integrated optics, grating coupler, photodetector, polarization diversity.**

I. INTRODUCTION

High refractive index contrast is the route towards very dense integrated optical circuits. Main applications for these optical chips are communication and sensing. In the last few years, a lot of very compact devices have been demonstrated in high vertical index contrast Silicon-on-Insulator (SOI) [1]. However, active devices are still difficult in silicon, due to its indirect band gap.

A possible solution is to heterogeneously integrate III-V material on Silicon. Active devices are then fabricated in the III-V material and coupled to the underlying silicon (with passive devices) [2, 3].

Another solution, which is explored in this paper, is to perform all functionality (passive and active) in III-V material. This approach avoids the need of integrating different material systems and the coupling between them. We use a wafer bonding technique to achieve the high vertical index contrast, needed for compact devices.

We demonstrate an efficient optical link in InP-membrane from fiber to detector, consisting of a grating coupler (coupling with the fiber), waveguides and on-chip photodetectors. Additionally, the link can be made polarization independent using polarization diversity. This is important, since the light coming out of the fiber in a real system has an unknown polarization.

II. GRATING COUPLERS IN INP-MEMBRANE

We use gratings for efficient coupling on-chip waveguides with the outside world (optical fiber). Advantages of this approach are the large bandwidth, good alignment tolerances and the possibility for wafer scale testing. Due to the high refractive index contrast, the gratings can be very compact (12 µm x 12 µm). The principle is shown in Fig. 1 (left) for incoupling. A 2D-simulation (outcoupling) is shown in Fig. 1(right). The layer structure consists of a thin (300 nm) high refractive index InP-membrane layer surrounded by low index material (air and the polymer BCB).

F. Van Laere is with the Information Technology Department (INTEC), Ghent University (UGent), Gent, Belgium. E-mail: frederik.vanlaere@intec.ugent.be .

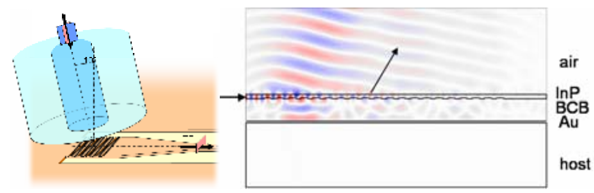

Figure 1. (left) Coupling to on-chip waveguides using grating couplers. (right) Simulation of such a grating coupler.

A bottom gold mirror is used to improve the coupling efficiency. We have demonstrated a fiber-to-waveguide coupling efficiency of 56% for this type of grating couplers [4].

III. DETECTORS

After the light is coupled to a waveguide it is guided to a functional device. An example of such a device is a wavelength demultiplexer, separating different wavelengths. In the end, the optical signal (light) has to be detected and transformed into an electrical signal (current). This can be done by integrating photodetectors on the chip. A simulation result of such a detector structure is shown in Fig. 2.

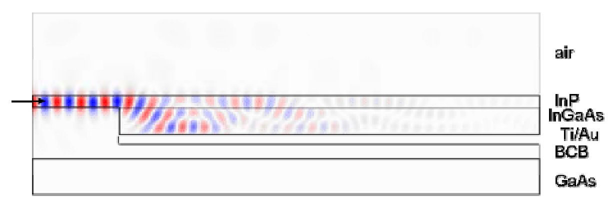

Figure 2. Simulation of an integrated photodetector. Only the bottom contact is taken into the simulation

The light in the InP-membrane waveguide layer is evanescently coupled to the underlying absorbing InGaAs layer. In a few roundtrips (see Fig. 2) all the light is absorbed in the InGaAs layer and a photocurrent is generated. A detector length of 10 µm is sufficient for detecting all the light.

IV. FABRICATION

The layer stack consists of (from top to bottom) a 80 nm highly p-doped InGaAs layer, a 500 nm intrinsic InGaAs absorbing layer, a 300 nm n-doped InP-membrane layer and a 500 nm InGaAs etch-stop layer on an InP-substrate. Pictures of the sample at different stages of the processing are shown in Fig. 3. First, detector mesas are defined and etched (Fig. 3a).

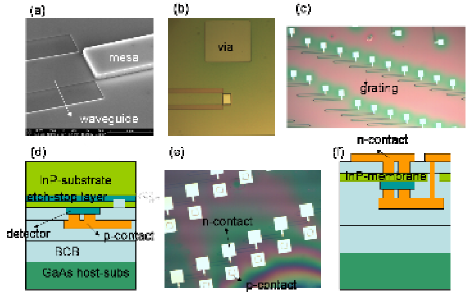

Figure 3. Pictures of the sample at different stages of the processing.

In the following step, gratings and waveguides are aligned to the detector mesas using a reproducible and controlled e-beam lithography process (Fig. 3a-b). After etching of the pattern, the p-contact for contacting through a via hole is defined (Fig. 3c). The sample is then bonded onto a GaAs host-substrate using an approximately 1 µm BCB layer (a polymer) (Fig. 3d). After curing of the BCB for 1 hour in a nitrogen environment, the etch stop layer and the InP-substrate are removed. Finally, the n-contact is defined and the access to the p-contact (at the bottom now) is provided (Fig. 3 e-f).

V. Detector Characterization

We have characterized the detectors by measuring the I-V curves for different input powers. A standard single mode fiber, connected to a tunable laser is positioned (at 8 degrees from vertical in order to avoid reflections) above the gratings. The light is first coupled to a waveguide by the grating and is finally evanescently coupled to the detector. The gratings used in this single waveguide configuration are very polarization selective, so we use polarization control wheels to select the TE-polarization (electric field parallel to the grating lines) The results for a 12 µm x 10 µm detector are shown in Fig. 4. The dark current is 4nA at -0.5 V reverse bias. The responsivity (fiber-to-detector) is 0.4 A/W. The grating coupler efficiency is estimated to be 30-40%. We have also measured the grating coupler spectrum using the detector. The result is shown in the inset of Fig. 4.

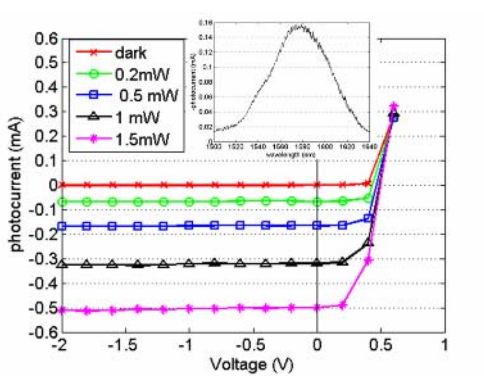

Figure 4. I-V measurements of the integrated photodetector. (inset) grating coupler spectrum

VI. Polarization Diversity

Gratings in a single waveguide configuration are very polarization sensitive (see previous paragraph). However, polarization independent operation can be obtained when using 2D-gratings in a polarization diversity configuration. We have demonstrated this approach in BCB-bonded InP-membrane with a grating coupler efficiency of 47% and a Polarization Dependent Loss (PDL) of 0.79 dB [5]. In that case, measurements were performed from fiber to fiber (input grating to output grating). Here, we have implemented the same approach, from fiber to detector. The layout of the sample is shown at the inset of Fig. 5. A 2D-grating is put in the intersection of two (near) orthogonal waveguides. For symmetry reasons, both orthogonal polarization components from the light in the fiber couple to the TE-mode of their own waveguide. At the output, both arms are recombined in a detector. For the measurement, a fiber, connected to a tunable laser is again positioned over the input grating. The photocurrent is measured (reverse bias voltage of -0.5V) while changing the polarization of the input light randomly, using polarization control wheels. This results in a Polarization Dependent Loss (I_{max}/ I_{min}) of only 0.35 dB. The measurement is also shown in Fig. 5.

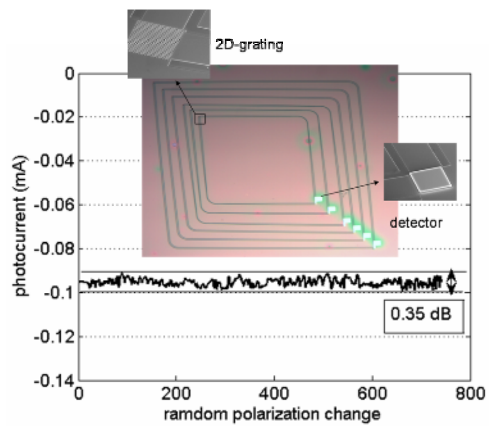

Figure 5. Polarization diversity using 2D-gratings and (near) orthogonal waveguides.

VII. Conclusions

We have demonstrated fiber grating couplers in high vertical index contrast BCB-bonded InP-membranes, integrated with efficient photodetectors. The fiber-to-detector efficiency is 0.40 A/W. Additionally, we have implemented polarization diversity with integrated photodetectors using 2D-grating couplers. PDL is measured to be 0.35 dB (fiber to detector). The cheap vertical fiber coupling, combined with efficient waveguide detectors, has potential for use in future telecommunication networks.

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