

Grating coupled photonic crystal demultiplexer with integrated detectors on InP-membrane

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Abstract— We report on the successful integration of grating fiber couplers, compact photonic crystal demultiplexers and efficient p-i-n photodetectors on a single bonded InP-membrane chip. Polarization independent operation is obtained by implementing polarization diversity.

Keywords-component; InP-membrane; photonic crystal; grating coupler; photodetector.

I. INTRODUCTION

Integration and miniaturization is the route towards ultra-dense integrated circuits at an acceptable price. Silicon-on-Insulator (SOI) is emerging as an interesting platform for realizing very compact photonic components, due to its high refractive index contrast [1-2]. However, active functionalities remain awkward on silicon. Therefore, an attractive approach is to combine the membrane-based approach (high refractive index contrast) with the active functionality of InP.

In this paper, we present experimental results for a graded suite of compactly integrated InP-membrane devices, suited for application in Coarse WDM metro-networks. The core device is a compact photonic crystal demultiplexer on InP-membrane, with integrated p-i-n photodetectors. Light is coupled from the fiber to the device using compact grating couplers [3-4], which can also implement polarization diversity.

II. BCB-BONDED INP-MEMBRANES

Standard InP/InGaAsP heterostructures have a limited vertical refractive index contrast. In order to achieve the high vertical index contrast, needed for compact devices we exploit BCB wafer bonding [5]. A patterned InP-die is therefore bonded, with the epi-layers down, onto a host-substrate using

the polymer BCB. After curing of this BCB, the original InP-substrate is lapped and etched away. The resulting basic structure is a thin InP-membrane (in our case 300 nm) surrounded by low-index material (air and BCB ($n=1.54$ at $\lambda=1.55 \mu\text{m}$)), as shown in Figure 1.

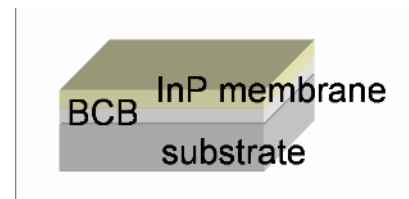


Figure 1. InP membrane obtained by BCB wafer bonding.

III. GRATING COUPLED PHOTONIC CRYSTAL DEMULTIPLEXER

We have implemented an ultra-compact photonic crystal (PhC) based demultiplexer on InP-membrane, for application in coarse WDM systems. The device is the first membrane version of the demultiplexer previously described in [6] for conventional InP heterostructures. It exploits the modal conversion at mini-stopbands (MSB) in a multimode photonic crystal waveguide (W5 in our case). SEM-pictures of the device prior to bonding are shown in Figure 2.

Light is coupled (near) vertically from a fiber into a membrane waveguide using grating couplers [3-4]. This signal feeds into a multimode photonic crystal waveguide. The fundamental mode couples to a higher order mode only in the MSB. The higher order mode is extracted by thinning one of the photonic crystal walls to a few rows of holes. Wavelength selectivity is obtained by varying the width of the PhC guide, which determines the central frequency of the MSB.

We have measured the device, consisting of 7 wavelength channels, spaced by 10 nm. The light at the output channels is

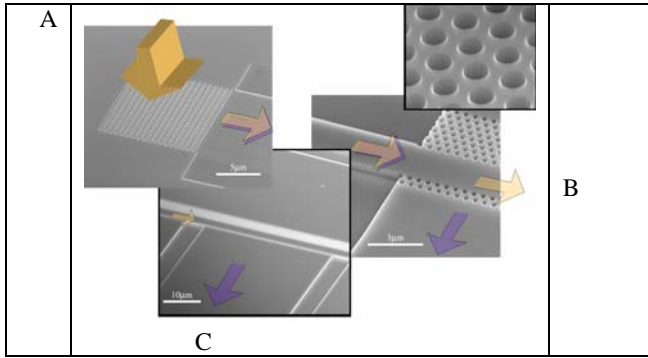


Figure 2. Grating coupled photonic crystal demultiplexer (prior to bonding). Light launched from a cleaved fiber is incoupled to a broad guide (A), tapered to a thin guide and enters the selective PhC guide (B). Demultiplexed signals are extracted through a thinned PhC wall.

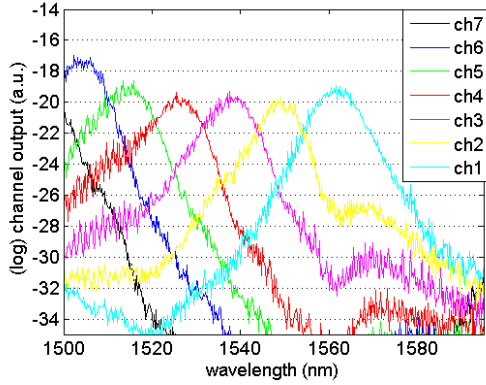


Figure 3. Measured channel output from the PhC demultiplexer.

collected at a cleaved facet. The crosstalk between adjacent CWDM channels (whose spacing is 20nm, $\Delta(\#ch)=2$ in Fig.3) is 7-8 dB. Measured spectra are shown in Figure 3.

IV. INTEGRATION OF DETECTORS ON INP-MEMBRANE

We worked out a detailed integration scheme for integrating p-i-n photodetectors onto the InP-membrane platform. A simulation of the designed detector structure is shown in Figure 4. Light from an InP-membrane waveguide (left on the figure) is coupled to an underlying absorbing InGaAs layer within a length adequate for most other purposes (speed, diversity scheme compatibility, sensitivity, width).

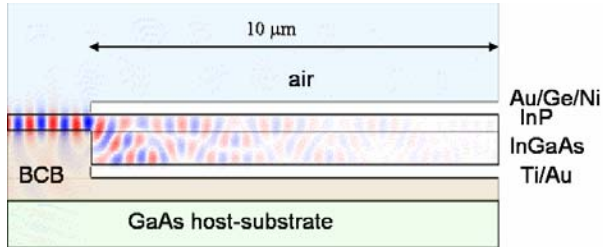


Figure 4. Eigenmode expansion simulation of a p-i-n detector integrated on an InP-membrane platform at 1550 nm central wavelength.

The layer structure consists of (from top to bottom) a 80 nm highly p-doped InGaAs layer, a 500 nm intrinsic InGaAs layer, a 300 nm (slightly) n-doped InP-membrane layer, a 500 nm InGaAs etch-stop layer on an InP-substrate. Pictures of the sample at different stages of the processing are shown in Figure 5. First, detector mesa's are defined using optical lithography and etching until the InP-membrane layer is reached. In the following step, gratings and waveguides are defined, aligned to the detector mesa's, using e-beam lithography. This pattern is etched to a depth of 90 nm into the InP-membrane layer. Large vias (50 x 50 μm^2) are defined using optical lithography, and etched completely through the InP-membrane layer (300 nm). A picture of this structure is shown in Fig. 5(a-b). In the next step, a 700 nm BCB layer is spin coated onto the sample for passivation. After curing of the BCB, p-contact windows are opened, and a Ti/Au (20nm/200nm) p-contact, also covering the via, is deposited using lift-off (Fig. 5c). The die is then flipped and bonded onto a GaAs host-substrate using another (approximately 1 μm thick) BCB layer (Fig. 5d). After curing for 1 hour at 250°C in a nitrogen environment, the InP-substrate is removed (using lapping and wet etching) until the etch-stop layer is reached. Then, the etch stop layer is removed using wet etching. Finally, another passivation BCB layer is spin coated onto the sample. After curing, n-contact windows are opened and the access to the bottom p-contact is provided by etching the via (now filled with BCB) until the p-contact. Finally a Au/Ge/Ni n-contact is deposited using lift-off (Fig. 5e-f).

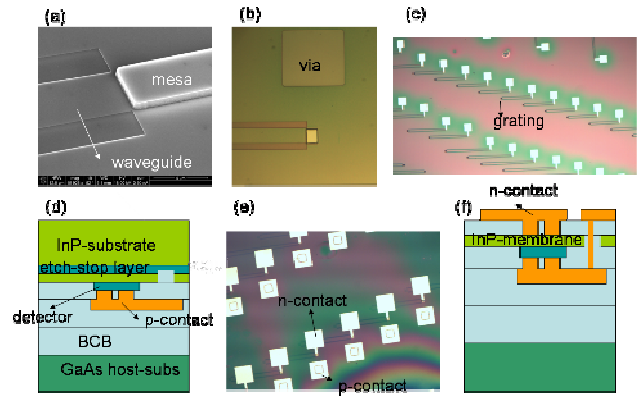


Figure 5. Pictures at different stages of the processing. (a) After InP-etching. (b) After via-etching. (c) After p-contact metallization. (d) Bonding of the sample. (e) After n-contact metallization. (f) Final detector structure.

The dark current of the detector is a low value of 4 nA at -0.5V reverse bias, and the external responsivity (fiber-to-detector, using grating couplers) is as much as 0.4 A/W.

V. INTEGRATION OF DETECTORS ON INP-MEMBRANE

We have integrated the demultiplexer from section III with photodetectors. The layout can be seen in Figure 6 and the measured photocurrent at the detectors in Figure 7. The "trough" in the through-signal is caused by the aggregated dropping of the wavelengths in the channels. Crosstalk values are comparable to the all-optical version.

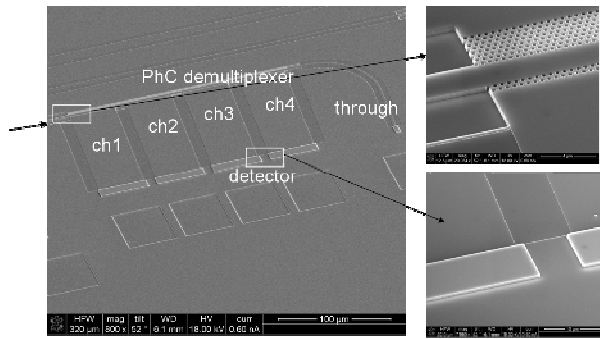


Figure 6. Photonic Crystal demultiplexer with integrated photodetectors (picture prior to bonding).

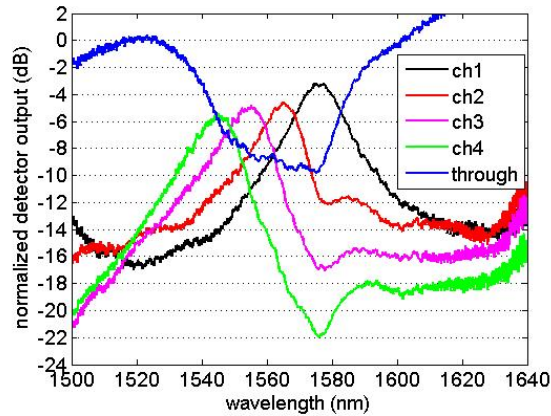


Figure 7. Photocurrent measured at the channel and through-detectors of the PhC demultiplexer.

VI. POLARIZATION DIVERSITY

Polarization is hard to tame in nanophotonics. The on-chip optical components are especially polarization sensitive when using high refractive index contrast, so, even when the fiber-to-chip coupling can be made polarization independent, the very nanophotonic components cannot. This demands in turn delicate on-chip polarization splitters and rotators. This problem is solved here by implementing polarization diversity. A practical test realization is shown in Figure 8.

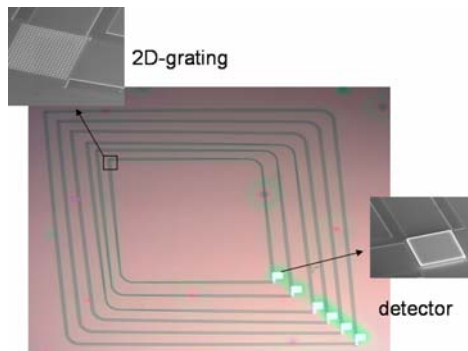


Figure 8. Polarization diversity test from 2D-grating couplers to detectors.

Light from the fiber is again coupled (near) vertically using a 2D-grating. The two orthogonal polarization components are separated at the grating coupler [7] and couple to the TE-mode of their own waveguide. Both arms recombine in the same detector.

The Polarization Dependent Loss is determined by measuring the maximum variation in photocurrent on the detector, when varying the polarization of the input light over all states. This measurement (at the center wavelength of the grating coupler spectrum) is shown in Figure 9, where we measure a PDL of only 0.35 dB.

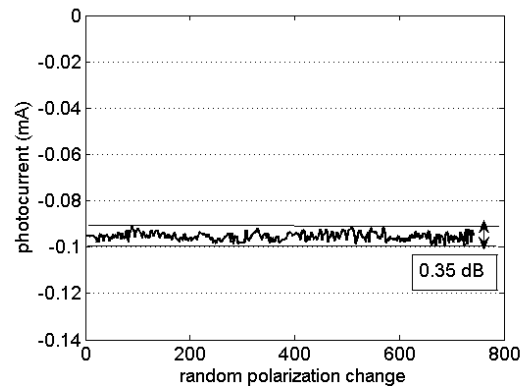


Figure 9. PDL measurement upon random manual changes.

VII. POLARIZATION DIVERSITY PhC DEMULTIPLEXER

In a final demonstration, we have implemented the PhC demultiplexer in a polarization diversity scheme. The layout is shown in Figure 10. The input light is split in its two orthogonal polarization components at the surface coupler. The demultiplexer is duplicated (one for each polarization) and the channel outputs are measured at a common detector.

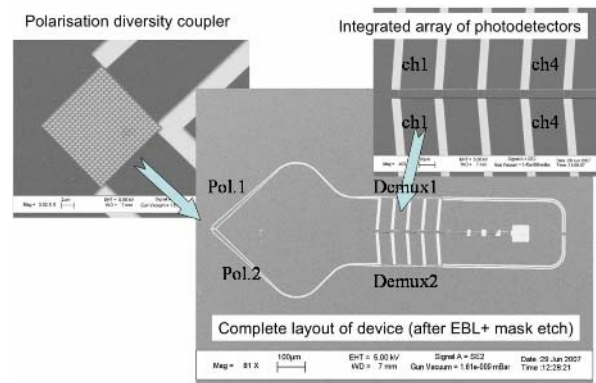


Figure 10. Full chip : Polarization diversity PhC demultiplexer with integrated photodetectors.

We have measured this device from CW up to 50 MHz modulation of the input light (higher speeds could not be measured, since we could only use DC probes). The result is shown in Figure 11.

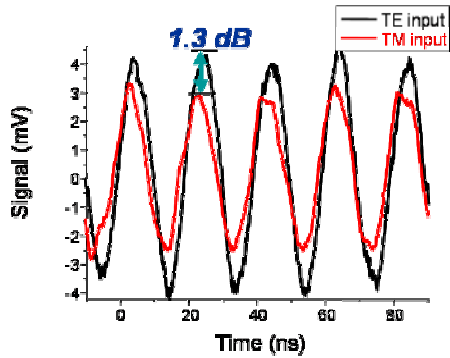


Figure 11. Measurement of the polarization diversity PhC demultiplexer with integrated photodetectors.

The input light was modulated at 50 MHz, and the electrical output was measured at the detector channels. The input modulation is clearly followed at the output. For this particular channel, the full chip PDL was still as low as 1.3 dB.

VIII. CONCLUSION

We have demonstrated a grating coupled photonic crystal demultiplexer with integrated detectors on InP-membrane, suited for application in CWDM metro networks. Future work will concentrate on improving the crosstalk of the demultiplexer. Polarization diversity using 2D-grating couplers is used to overcome the polarization sensitivity of the device.

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