Multifunctional Photonic Crystal Compact Demux-Detector on InP

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Abstract: We demonstrate a very compact multifunctional photonic crystal device on InP-membrane. Grating-coupled fibers feed a multimode photonic crystal wedged waveguide accomplishing individually selectable coarse WDM demux within 20 µm per channel toward membrane integrated detectors.

OCIS codes: (130.0130) Integrated Optics; (040.5160) Photodetectors; (050.2770) Gratings; (230.0230) Optical Devices

1. Introduction

High refractive index contrast is the route towards very dense integrated circuits. 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. Recently, III-V material was heterogeneously integrated on Silicon, in which lasers and detectors were fabricated and coupled to the underlying silicon [2-3]. Also, very high performance detectors in epitaxially grown Germanium on Silicon were demonstrated [4].

In this paper, both active and passive functionalities are integrated in III-V material. The high vertical index contrast, needed for compact devices, is obtained by benzocyclobutene (BCB) wafer bonding [5]. Light is coupled vertically from the fiber to the device using small, i.e. fiber-core-sized, grating couplers. Polarization independent operation using polarization diversity is experimentally substantiated. As an application, we demonstrate a very compact photonic crystal demultiplexer in InP-membrane integrated with waveguide photodetectors, well suited for Metropolitan Area Networks.

2. Device

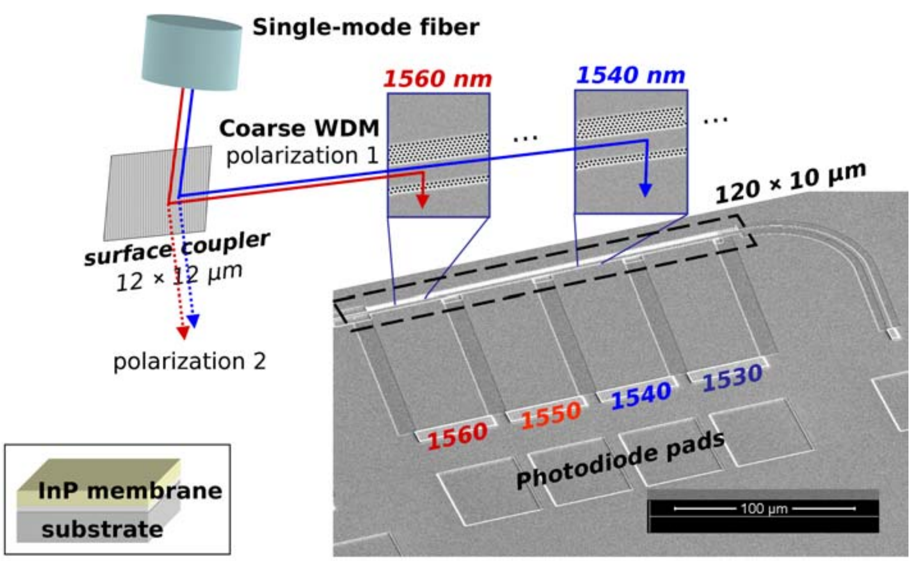

Fig. 1. Scheme of the compact demultiplexer technology embedded onto an InP-membrane.

The global device layout is shown in Fig. 1. The basic layer stack is a 300 nm-thick InP-membrane sandwiched between air and BCB (a low index polymer, n = 1.54 at 1.55 µm) on a host-substrate. Compact (12×12 µm) surface grating couplers are used to inject light (near) vertically from single-mode fiber to waveguide [6]. Polarization diversity deals with the different fiber polarizations which are separated at the surface coupler [7]. The multiplex signals travel in a guide that becomes a highly specific multimode photonic crystal waveguide. This waveguide itself performs the spectrometer-demux action, as sketched here for two wavelengths, 1540 and 1560 nm. The optical carriers then reach a set of decoupled photodiodes, suited to provide telecom-rate photocurrents. In the following paragraphs we will describe the different components of the device in more detail.

3. Integrated p-i-n detectors on InP-membrane

The layout of the p-i-n detector and the detector coupling principle are shown in Fig. 2. The light is first coupled from a single-mode fiber to an InP-membrane waveguide (slightly n-doped) by a compact grating coupler (Fig. 2 left) [6]. Coupling from InP-membrane waveguide to an underlying 500 nm InGaAs detector layer (Fig. 2 middle) is done evanescently. The first steps of the integration scheme involve detector mesa definition, followed by e-beam lithography of waveguides, photonic crystals (PhC), and gratings aligned to the mesas. After p-contact definition, the structure is bonded onto a host-substrate using BCB wafer bonding. After substrate and etch-stop layer removal, the n-contact is defined and access to the p-contact (now at the bottom side) through a via is provided. A cross-section of a fabricated detector structure is shown in Fig. 2 (right).

The measured dark current of the detector (12×10 µm in this case) is 4 nA at V_R = 0.5 V reverse bias and the external responsivity (fiber to waveguide to detector) is η = 0.40 A/W. The grating coupler efficiency is estimated to be 30–40%, which could be further increased by adding a bottom mirror to the grating [8].

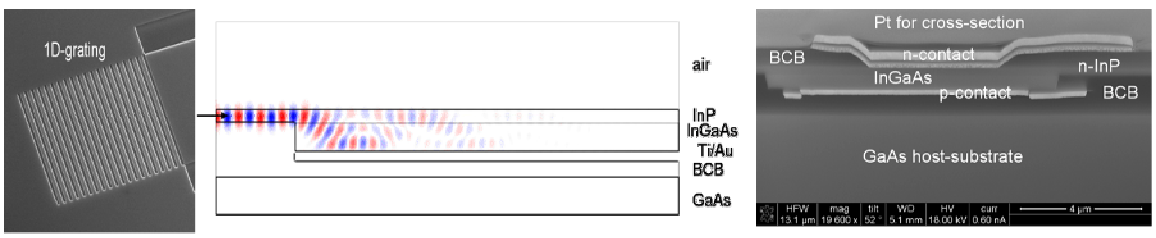

Fig. 2. (Left) Input grating coupler. (Middle) Simulation of the waveguide-to-detector coupling (only p-contact taken into account). (Right) Cross-section of a fabricated structure (p-contact access through via not shown here).

4. Polarization diversity using grating couplers

Gratings in a single waveguide configuration (previous section) are nearly perfectly polarizing. Thus, polarization-independent operation can be obtained when using 2D gratings in a polarization diversity configuration [7]. We have implemented this approach, from fiber to detector. A 2D grating is put in the intersection of two near orthogonal waveguides. 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 (Fig. 3 left). For the measurement a fiber connected to a tunable laser is 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 a polarization controller. This results in a polarization diversity loss (PDL) figure (I_{max}/I_{min}) of only 0.35 dB (Fig. 3 right).

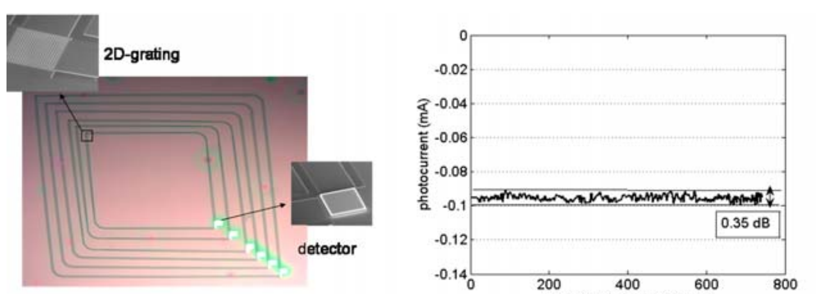

Fig. 3. Polarization diversity using 2D grating couplers. (Left) Sample layout prior to bonding. (Right) PDL measurement.

5. Photonic crystal demultiplexer

We implemented an InP-membrane version of the PhC demultiplexer of Refs. [9-11]. It exploits resonant intermodal coupling at mini-stopbands (MSB) of a multimode PhC waveguide ("W5" here). The carrier converted in a higher-order mode is directionally extracted by thinning a PhC lateral cladding. Demux operation is obtained by adapting the local PhC guide width to tune the MSB central frequency in a fully selectable manner (unlike phasars). A section length of ~ 20 µm is enough for good extraction, resulting in an extremely compact device. The layout of Fig. 1 has 10 nm-spaced channels. A tunable laser is coupled by a grating (one-dimensional here). The carriers are extracted in 4 broad channels towards integrated photodiodes, where photocurrent is measured. The through signal feeds a last integrated detector. The results are shown in Fig. 4 (middle). Channel 1 is absent due to a damaged contact pad. The crosstalk is ~ –10 dB for nonadjacent channels in this first realization, with known margins for progress from all-optical tests (insets). The shape of the through signal evidences (Fig. 4 right) the selectable device action.

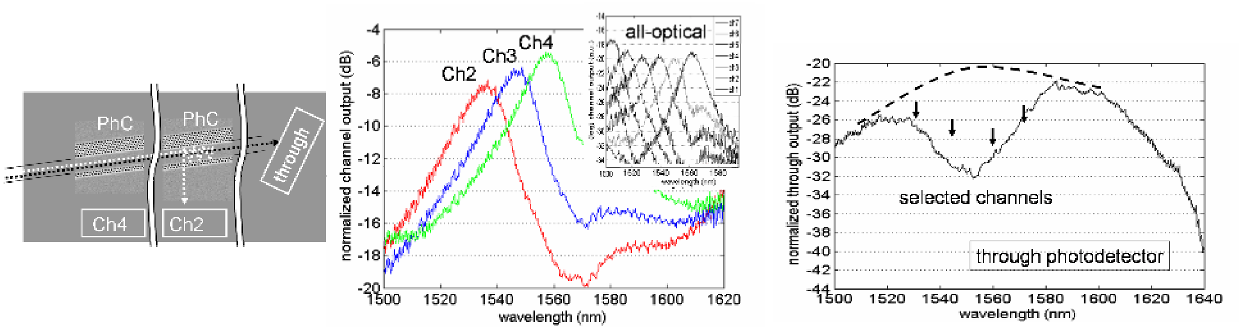

Fig. 4. (Left) Photonic crystal demux with integrated photodetectors. (Middle) Photocurrent of the channels, normalized to the grating coupler spectrum; inset: similar 7-channel all-optical measurement. (Right) Measurement of the through waveguide. The dashed line is a guide to the eye.

6. Conclusions

We have demonstrated a very compact multifunctional photonic crystal demultiplexer for coarse WDM in bonded InP-membrane, integrated with InGaAs p-i-n photodetectors. The interface with the outside world (fiber) is provided by efficient and compact grating couplers. Polarization diversity and crosstalk improvements of this realization show that a compact photonic crystal real-world integrated telecom device is a genuine technological option.

Acknowledgements

This work was supported by the European Union through the FP6-IST-004582 FUNFOX project. The Fraunhofer Institüt für Nachrichtentechnik, Heinrich-Hertz Institüt, Berlin is acknowledged for providing the epiwafers.

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