Miniature Integrated Spectrometer Fabricated on a Silicon-on-Insulator Substrate

Joost Brouckaert, Gunther Roelkens, Shankar Selvaraja, Wim Bogaerts, Pieter Dumon, Steven Verstuyft, Zon-Qiang Yu, Dries Van Thourhout and Roel Baets
Ghent University – IMEC, Department of Information Technology (INTEC), Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium
Joost.Brouckaert@intec.UGent.be

Abstract—**We demonstrate a compact and cost-effective 30-channel integrated spectrometer fabricated on a nanophotonic silicon-on-insulator (SOI) platform. The spectrometer consists of a planar concave grating (PCG) demultiplexer with heterogeneously integrated III-V photodetectors. The device has a resolution of 3.2nm and a small footprint of ~2mm^2. The photodetectors have a dark current of ~3nA at 5V bias and a responsivity of 1A/W. The on-chip loss for the central PCG channels is 3dB, resulting in an on-chip responsivity of 0.5A/W.**

I. Introduction

PLANAR waveguide spectrograph type (de-)multiplexers like arrayed waveguide gratings (AWGs) and planar concave gratings (PCGs) are essential components in WDM telecommunication networks and with increasing resolution and channel count, these devices could also find application in integrated microspectrometers. We previously demonstrated that the nanophotonic silicon-on-insulator (SOI) platform is a very interesting candidate for the fabrication of very compact, low-cost and high performance PCGs [1].

In this letter, we demonstrate a microspectrometer consisting of a PCG demultiplexer fabricated on an SOI substrate with heterogeneously integrated InGaAs photodetectors. These photodetectors are integrated by means of bonding unprocessed III-V dies (epitaxial layers down) onto the processed SOI wafer using DVS-BCB as an intermediate adhesive layer. After substrate removal, the detectors can be fabricated on a wafer scale and lithographically aligned to the underlying SOI waveguides [2]. This integration technique, in combination with the fabrication of the passive circuitry on low-cost SOI wafers using CMOS compatible processes could result in a compact, highly integrated and low-cost miniature photospectrometer.

II. Design and Fabrication

The heart of the spectrometer is a 30-channel planar concave grating (PCG) demultiplexer (Fig 1.). It is fabricated on a 200mm SOI wafer with a 220nm thick Si top layer using

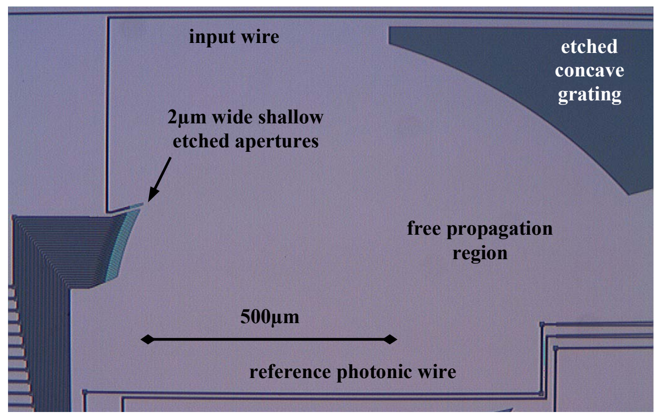

Fig. 1. Microscope picture of the 30-channel PCG demultiplexer.

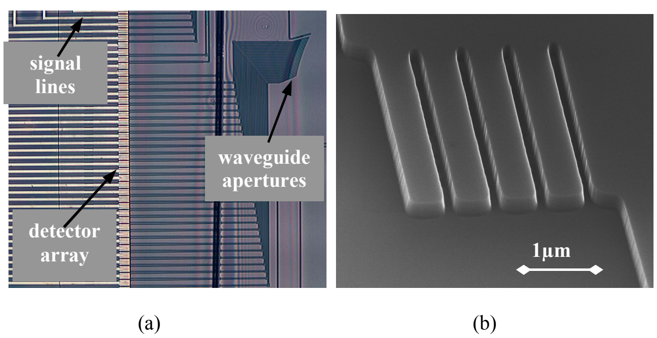

Fig. 2(a) Picture of the detector array processed on the output waveguides of the PCG demultiplexer and (b), a SEM picture of a DBR grating facet.

193nm deep-UV lithography in combination with ICP-RIE etching [3]. The design is based on the Rowland geometry: the input and output waveguides are positioned on a circle with a radius of 554µm and the curved grating sits on an 1108µm radius circle. The order of diffraction is 10 and the entrance and exit waveguides are 2µm wide with a spacing of 5µm between the centers of the output waveguides along the Rowland circle. These waveguides are shallowly etched (70nm deep) and a double adiabatic taper is used to convert to deeply etched 500nm wide photonic wire waveguides. To avoid excessive reflection loss at the grating facets, we replaced the 141 flat facets with second order distributed Bragg reflector (DBR) facets [4] (Figure 2b). This method

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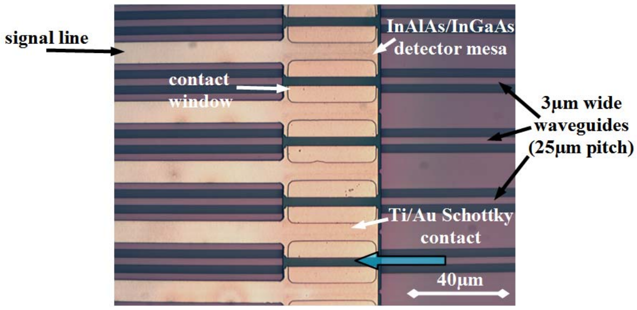

Fig. 3. Detailed top-view picture of the MSM photodetectors on top of 3µm wide SOI waveguides.

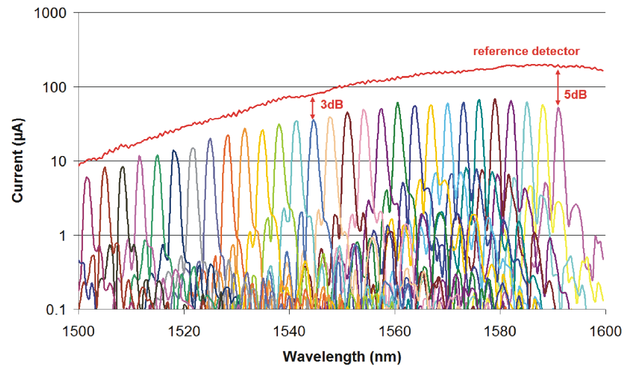

Fig. 4. Photocurrent spectrum of the 30-channel spectrometer and reference photodetector (red line) for TE polarized light. Only the sidelobes of the first channel (at λ=1499) are visible.

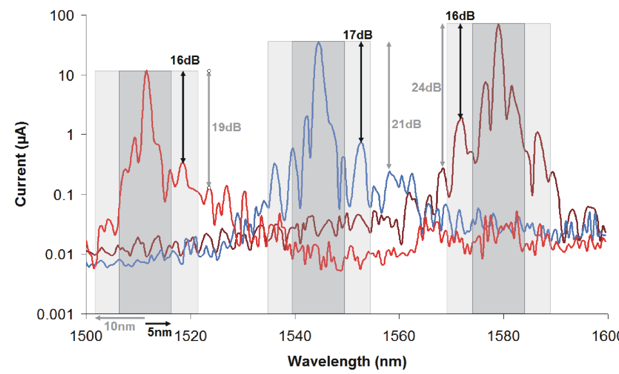

Fig. 5. Photocurrent spectrum and optical extinction ratio (both short and longer range) of channel 5, 15 and 26.

allows reducing the on-chip loss without the need of extra processing [4].

Evanescently coupled InGaAs/InAlAs metal-semiconductor-metal (MSM) photodetectors were integrated on top of the 30 output waveguides (Fig 2a). To obtain efficient coupling, the DVS-BCB bonding layer between the SOI waveguides and the MSM detectors is only 130nm thick. Processing, simulation and measurements of these photodetectors are described elsewhere [2]. Detectors with a length of 40µm have a responsivity of 1A/W at 1.55µm and a dark current of ~3nA at 5V bias. The detector pitch is 25µm as can be seen in figure 3. The size of the spectrometer including photodetectors, but excluding electrical probe pads is ~2mm^2.

III. Measurement Results

Light was coupled into the SOI chip using fiber couplers [3]. These are shallowly etched 1-D gratings which allow coupling light from a single mode fiber into the nanophotonic waveguides. Figure 4 shows the photocurrent spectrum of both the spectrometer and a detector which is processed on top of a reference waveguide. As the quantum efficiency of the detectors is almost constant from 1.5 to 1.6µm, the spectrum of the reference detector is mainly determined by the fiber coupler transmission. These couplers have an estimated minimal coupling loss of 6dB at a wavelength of 1590nm and a 3dB bandwidth of 65nm. The on-chip loss (in respect to the reference detector) of the PCG ranges from 3dB for the central channels to 5dB for the longest wavelength channel as can be seen in figure 4. The power budget can be calculated as follows. By fine-tuning the fiber coupler, it is possible to make the central PCG wavelength and the maximum fiber coupler transmission coincide at 1.55µm. The total loss for the central channels is about 6dB (fiber coupler loss) + 3dB (on-chip PCG loss). Waveguide loss can be neglected. Taking into account a detector responsivity of 1A/W at 1.55µm, the total responsivity for the central channels is ~0.1A/W. Due to the simultaneous processing of the detectors, there is no major variation of both the dark current and the responsivity for different detectors as can be seen in figure 5.

The near-channel optical crosstalk varies between -10dB and -18dB. To assess the longer range extinction ratio between the different spectrometer channels, we plotted the photocurrent of channels 5, 15 and 26 as can be seen in Figure 5. The extinction ratio outside a 5nm range of each channel is better than 15dB, and >20dB outside a 10nm range.

IV. Conclusions

We demonstrated a very compact (2mm^2) near-infrared 30-channel spectrometer based on the heterogeneous integration of III-V photodetectors on SOI PCGs. As these photodetectors can be processed on a wafer scale on cheap and high quality SOI substrates, it opens the way for low-cost miniature spectrometers that can be mass-fabricated.

Acknowledgment

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References

[1] J. Brouckaert *et al.*, "Planar Concave Grating Demultiplexer Fabricated on a Nanophotonic Silicon-on-Insulator Platform," *Journal of Lightwave Technology*, vol. 25, pp. 1269-1275, 2007.

[2] J. Brouckaert *et al.*, "Compact InAlAs/InGaAs Metal-Semiconductor-Metal Photodetectors Integrated on Silicon-on-Insulator Waveguides," *Photonics Technology Letters,* vol. 19, pp. 1484-1486, 2007.

[3] W. Bogaerts *et al.*, "Basic structures for photonic integrated circuits in Silicon-on-insulator," *Optics Express*, vol. 12, pp. 1583-1591, 2004.

[4] J. Brouckaert *et al.*, "Planer Concave Grating Demultiplexer with High Reflective Bragg Reflector Facets," *Photonics Technology Letters,* vol. 20, pp. 309-311, 2008.