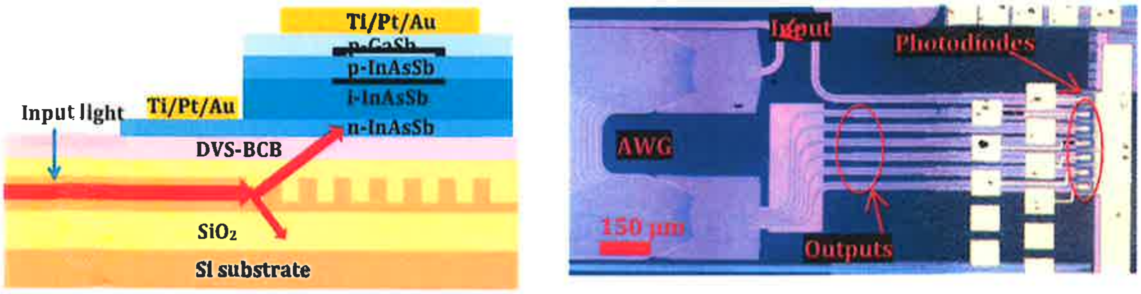
3.8 µm Heterogeneously Integrated III-V on Silicon Micro-Spectrometer

Anton VASILIEV[1,2*], Muhammad MUNEEB[1,2,3], Alfonso RUOCCO[1,2], Aditya MALIK[1,2], Hongtao CHEN[1,2], Milos NEDELJKOVIC[4], Jordi SOLER-PENADES[4], Laurent CERUTTI[5], Jean-Baptiste RODRIGUEZ[5], Goran MASHANOVICH[4], Meint SMIT[3], Eric TOURNIE[5] and Günther ROELKENS[1,2,3]
[1]Photonics Research Group, Ghent University-imec,
Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium
[2]Center for Nano- and Biophotonics, Ghent University, Belgium
[3]COBRA Research Institute, Eindhoven University of Technology,
Eindhoven 5600 MB, Netherlands.
[4]Optoelectronics Research Center, Faculty of Physical Sciences and Engineering,
University of Southampton, Southampton, UK
[5]Université de Montpellier, IES, UMR 5214, F-34000 Montpellier,
France and CNRS, IES, UMR 5214, F-34000 Montpellier, France
* Anton.Vasiliev@UGent.be

Hydrocarbon- and organic compounds have characteristic absorption features in the 3–4 µm wavelength range [1], and the detection and analysis of such compounds is of great importance for many practical applications. A number of discrete opto-electronic light emitters and photodetectors have already been demonstrated that allow realizing spectroscopic systems in this wavelength range [2,3]. The integration of such components on a photonic integrated circuit is essential for the miniaturization and cost reduction of spectroscopic sensor systems.

We demonstrate a compact (1.2 mm^2) fully integrated room-temperature mid-infrared spectrometer operating at ~3.8 µm. To our knowledge this is the longest wavelength integrated spectrometer working in the important wavelength window for hydrocarbon- and organic compounds spectroscopy. The spectrometer is based on a Silicon-On-Insulator (SOI) Arrayed Waveguide Grating (AWG) filter. An array of $InAs_{0.91}Sb_{0.09}$ p-i-n photodiodes is heterogeneously integrated on the spectrometer's output grating couplers using adhesive bonding. The AWG is defined using deep-UV lithography on a SOI wafer with 380 nm silicon device layer thickness and 2 µm buried oxide thickness.



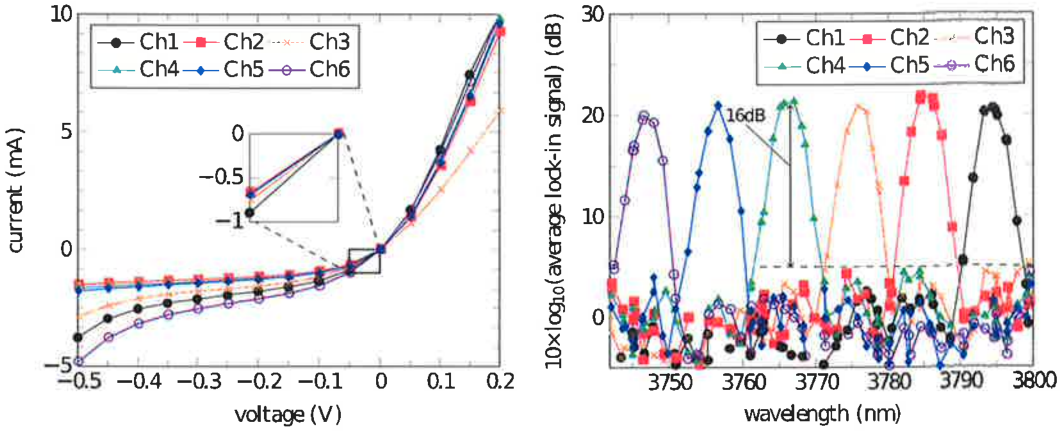
(a) (b)

Fig. 56. Schematic view of the cross-section of the bonded photodetector on top of the output grating coupler (a). Microscope image of the integrated spectrometer (b).

The waveguides are etched 160 nm deep and are cladded with SiO_2. Detailed description of the AWG design can be found in [4]. For the p-i-n photodiodes, an optimized InAsSb-based III-V epitaxial layer stack is fabricated using Molecular Beam Epitaxy (MBE). After planarization of the SOI sample, the III-V stack is bonded using a

300 nm thick DVS-BCB layer. The photodiode mesas (30x45µm²) are then lithographically defined on top of the output grating couplers of the AWG. A microscope image and schematic view of the cross section is presented in Fig. 1. Contacts are subsequently defined using e-beam evaporation. The complete structure occupies a total area not larger than 1.2 mm².

The integrated photodiodes have been electrically characterized at room temperature. The IV-curves of the 6 channel output photodiodes are shown in Fig. 2a. The average dark current is around 600 µA at -50 mV reverse bias. It is believed that the dark current can further be reduced by implementing barriers in the epitaxial layer stack and performing better passivation [5]. For optical characterization, chopped mid-infrared light from an Optical Parametric Oscillator (OPO) is coupled to a single-mode ZrF_4 fiber after which it is vertically coupled to the chip. The polarization is adjusted to TE by using a Babinet-Soleil compensator. To compensate for slow fluctuations of the OPO output power, the photodiode response is normalized to a fraction of the OPO output power which is monitored using a thermopile detector. The integrated photodiode response is measured using a pre-amplifier at zero bias. To further increase the signal to noise ratio, the output of the pre-amplifier is connected to a lock-in amplifier. The wavelength of the OPO is swept by controlling the crystal position using a stepper motor and adjusting the intra-cavity etalon angle.



(a) (b)

Fig. 2. IV-curves of the integrated photodiodes on the output ports of the AWG (a). Measured AWG response using lock-in detection (b). The crosstalk is around 16 dB.

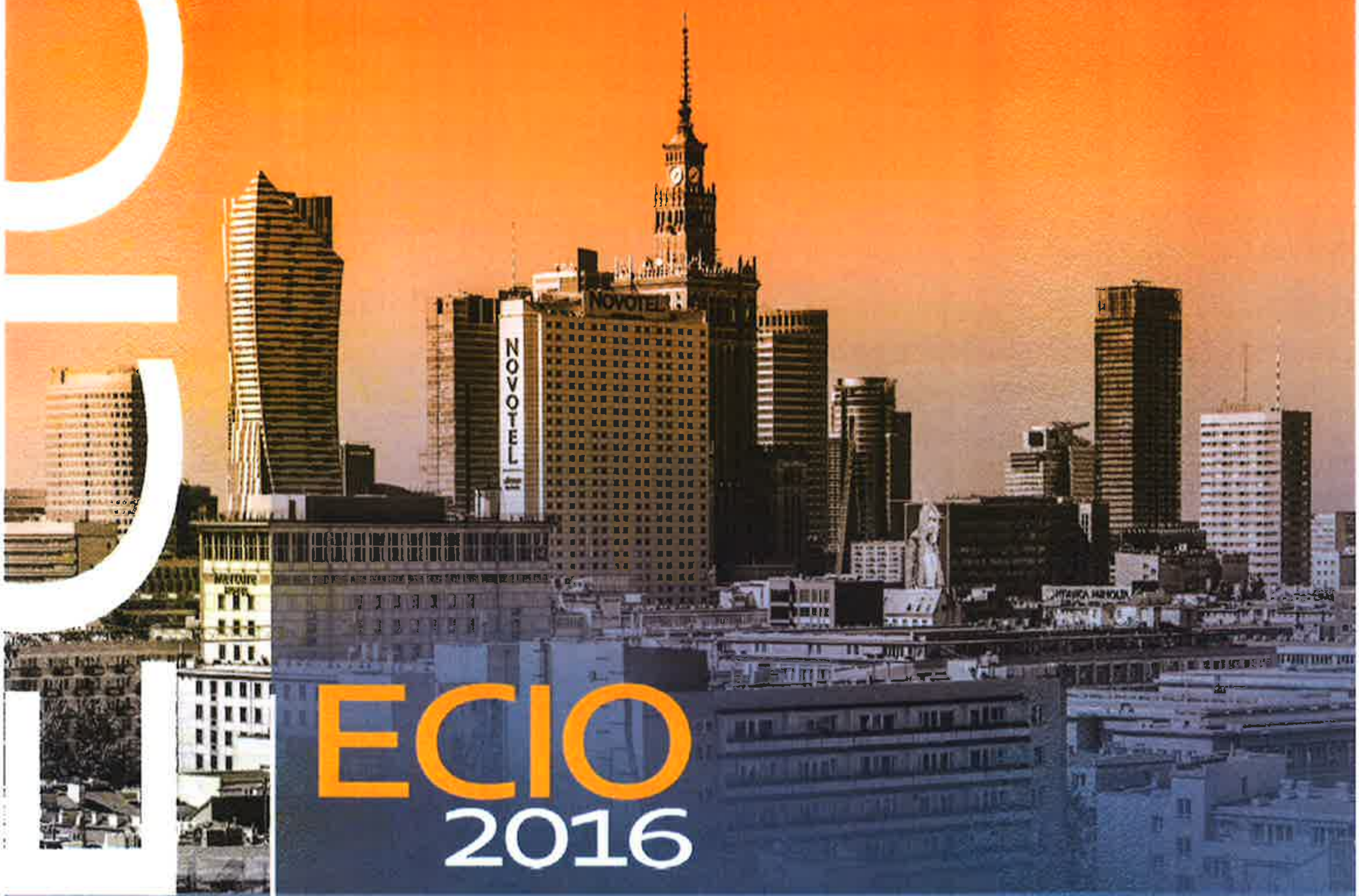
[1] P. Larkin, *Infrared and Raman spectroscopy; principles and spectral interpretation*. Elsevier, (2011)

[2] H. Ait-Kaci et al., *Optimization of InAsSb photodetector for non-cryogenic operation in the mid-infrared range*, Phys. Stat. Sol. (a) 202, No. 4, 647–651 (2005)

[3] G. Roelkens et al., *Silicon-based photonic integration beyond the telecommunication wavelength range*, IEEE J. Sel. Top. Quantum Electron., 20(4), p.8201511 (2014)

[4] M. Muneeb et al., *Demonstration of silicon on insulator mid-infrared spectrometers operating at 3.8 um*, Opt. Express, vol. 21, no. 10, pp. 11659–11669 (2013)

[5] A. Gassenq et al., *Study of evanescently-coupled and grating-assisted GaInAsSb photodiodes integrated on a silicon photonic chip*, Optics Express, 20(11), p.11665-11672 (2012)



ECIO
2016

18TH EUROPEAN CONFERENCE ON INTEGRATED OPTICS 2016

18–20 MAY | WARSAW | POLAND

SUPPORTED BY

CZIiTT

SKKP

CEZAMAT

EPIC