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Novel approach for the integration of photonic circuits with mid-IR detectors

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Currently, one of the main objectives within the mid-IR community consists of reducing the dimensions and cost of sensing systems. Photonic integrated circuits (PICs) have been indicated as valuable candidates to achieve these goals thanks to their compactness, low cost (e.g. using CMOS-compatible platforms) and to their large versatility for applications such as multiplexing/demultiplexing or high detection throughput [1], [2].

In particular, special attention needs to be devoted into how different building blocks of e.g. a sensing system are interfaced with each other.

Here, we present a novel integration technique where a PIC is interfaced with a mid-IR photodetector (PD) in a butterfly package. The PIC serves a mechanical purpose as part of the lid of the package wherein the mid-IR PD is mounted, while optically it acts as an IR bandpass window, which allows to filter out unwanted radiation. The latter function is achieved thanks to a grating coupler element as part of the PIC, which presents a selective transparent response (< 1 dB) around 3.3 μm. Besides this optical function, the PIC also allows to demultiplex an optical beam into its different wavelength components through the use of an arrayed waveguide grating (AWG) spectrometer. Furthermore, every arm of the AWG contains a thermo-optic modulator allowing to exploit only a single PD to recover the different wavelength components by sequential modulation of each AWG channel/arm [2].

The PIC is fabricated by imec in an SOI platform with 400 nm device layer thickness and with a single partial etch step of 180 nm to define waveguides. The detector used is an HgCdTe-based (MCT) photovoltaic detector with 0.8 A/W responsivity at 3.3 μm from Vigo System S.A., who also carried out the packaging assembly.

The assembly has been characterized using an optical parametric oscillator (OPO) system from Aculight. Light is coupled into the PIC by a grating coupler using a ZrF_4 single mode fiber. More information on the setup in [1]. The PD response is obtained by measuring the voltage provided by a transimpedance amplifier (TIA) with 7.6 kV/A gain connected to the output of the PD. Taking into account the insertion loss (IL) of ~ 8 dB for the input grating, IL of ~ 1-2 dB for the AWG filter and an IL ~ 1 dB for the output grating, we obtain an overall insertion loss from the fiber to the PD of ~ 10-11 dB. The original cross-talk of the AWG (~ 20 dB) can be recovered by modulating each channel of interest separately, retrieving only the modulated signal on the PD [2]. The fiber-to-fiber (2x grating coupler) insertion loss was measured to be 8 dB higher than for the mounted PIC with PD.

This result demonstrates the feasibility of such approach to integrate PICs and PDs into the same package, while at the same time removing bulky parts such as IR windows and providing additional functionality to PDs. Next measurements will be carried out, while modulating each channel separately for spectroscopic applications.

[1] A. Vasiliev et al., "High resolution silicon-on-insulator mid-infrared spectrometers operating at 3.3 μm," *Summer Top. Meet. Ser. SUM 2017*, pp. 177–178, 2017.

[2] A. Vasiliev et al., "Integrated Silicon-on-Insulator Spectrometer With Single Pixel Readout for Mid-Infrared Spectroscopy," *IEEE J. Sel. Top. QUANTUM Electron.*, vol. 24, no. 6, p. 8300207.

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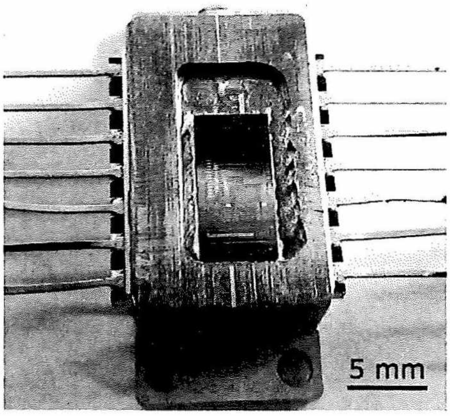

Fig. 1. High-level assembly of the integration of the PIC into a butterfly package, wherein the PD is located with a temperature controller (not visible).

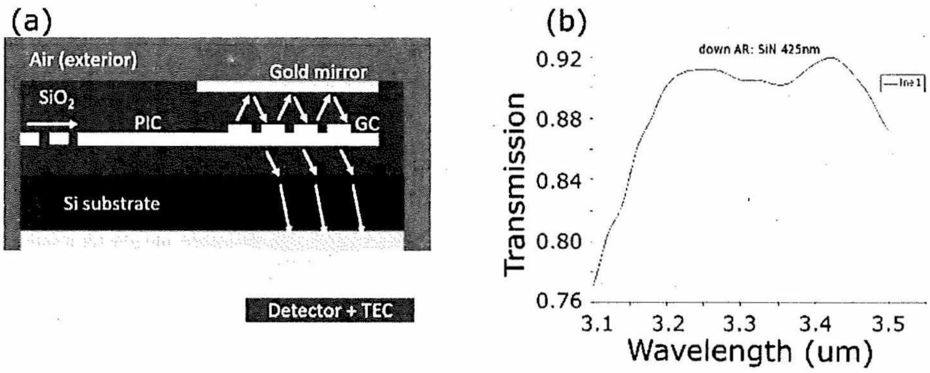

Fig. 2. Optical interface PIC to PD. (a) Schematic of how the light is collected by the PD through the grating coupler. Light is coupled into the PIC by an input grating coupler followed by the AWG circuit. (b) Grating response around 3.3 μm exploiting a metal Au mirror on top and an Si_3N_4 AR coating to enhance the efficiency. A lens, not drawn, is present above the PD to collect the light onto the PD.

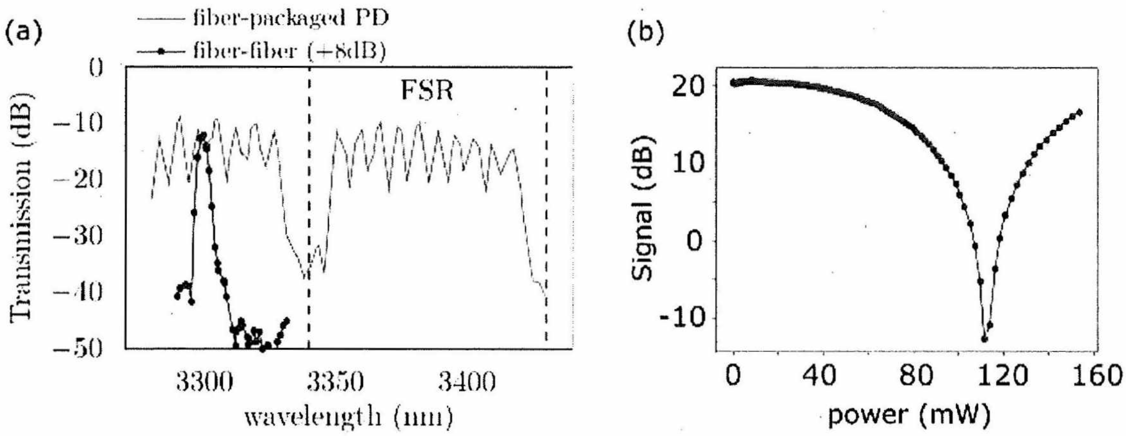

Fig. 3. Performance of the PIC. (a) Transmission of the packaged PIC with an AWG spectrometer. (b) Response of a reference Mach-Zehnder modulator (same design as those present on each AWG arm).

PHOTONIC SENSING

Session Chair: Marko Härtelt

16:00 – 16:30

8.1 Invited Paper: **Recent advances in mid-IR trace gas sensing architectures**
J. P. Waclawek, J. Hayden, S. Lindner, H. Moser, B. Lendl
Institute of Chemical Technologies and Analytics, TU Wien, Vienna, Austria

16:30 – 16:50

8.2 High-speed analysis of chemical processes using the IRis-F1 spectrometer based on quantum cascade laser frequency combs
P. Allmendinger, R. Horvath, P. Jouy, M. Mangold, M. Geiser, A. Hugi
IRsweep AG, Stäfa, Switzerland

16:50 – 17:10

8.3 IR detection by nonlinear-optical upconversion for highly time-resolved MWIR spectroscopy
S. Wolf[1], J. Kießling[1], V. Weiser[2], S. Knapp[2], F. Kühnemann[1]
[1] Fraunhofer Institute for Physical Measurement Techniques IPM, Freiburg, Germany
[2] Fraunhofer Institute for Chemical Technology ICT, Pfinztal, Germany

17:10 – 17:30

8.4 Novel approach for the integration of photonic circuits with mid-IR detectors
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17:30 – 17:45

Closing Remarks