# Laser and photodetector integration on Silicon-on-insulator waveguide circuits: towards a fully integrated SWIR spectrometer

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## BIOGRAPHY

**Alban Gassenq**: Born in Montpellier in 1983, he received his diploma in opto-electronic engineering from the University of Montpellier 2 (UM2) in 2006. He then worked towards a PhD degree in the Nanomir group of the Institut d'Electronique du Sud at UM2. He got the PhD degree in Semiconductors for MidIR applications in 2010. Now, he works in the Photonics Research Group of Ghent University – IMEC in Belgium on Mid-IR integrated optics.

## TECHNICAL ABSTRACT

The mid-IR is an interesting wavelength range enabling new applications for photonic integrated circuits. Silicon-on-insulator (SOI) waveguide circuits combined with III-V opto-electronic components provide a platform to realize a fully integrated spectrometer for sensing applications. The availability of an integration platform for this wavelength range could enable ultra-compact, low-cost sensor solutions that outperform existing solutions by their selectivity and sensitivity. For this objective, either a tunable laser source needs to be integrated or an SOI spectrometer combined with an array of photodiodes at its outputs is needed. In this work, we investigate this III-V integration on a silicon-on-insulator waveguide circuit for operation around a wavelength of 2.2µm, based on the GaSb material system. Different photodiode designs are studied, showing a high responsivity (>1A/W) and a dark current of 2µA at room temperature. The first integration of a photodetector array on top of a silicon-on-insulator planar concave grating (PCG) spectrometer is reported. For the GaSb-based laser, continuous wave (CW) operation is measured at room temperature for a bonded laser that is mechanically cleaved. Different possibilities to couple the laser emission into the silicon waveguide will be presented that allow the completion of the laser integration.

Regarding the integrated photodiode, the first implementation at 2.2µm has been demonstrated with a responsivity of 0.44A/W, through evanescent coupling between the silicon waveguide and the thin-film photodiode [1]. In this work, a detailed characterization and considerable improvement of these evanescently coupled devices is presented with a maximum responsivity of 1.4A/W [2]. Electrical characterization was also performed to assess the performance limiting factor. Sidewall leakage due to the BCB passivation was measured to contribute the most to the dark current. Furthermore, in view of the integration of large arrays of photodiodes on SOI spectrometer circuits, grating-assisted photodetectors were developed. Using a diffraction grating to interface the silicon waveguide with the photodetector, the measured responsivity was 0.4A/W, with a dark current of 3µA. Since this design is more tolerant to bonding layer thickness variations, larger area bonding with high yield can be envisioned to process photodiode arrays on the outputs of spectrometers with many channels.

The first results of the system integration are presented in this paper. The grating-assisted photodiodes were bonded on top of the outputs of a planar concave grating spectrometer presented in Figure 1-a [3]. This spectrometer is a planar concave grating (PCG) with 8 channels and 4 nm channel spacing operating around 2.2 µm. Showing similar electrical properties, the photodiodes can detect the light from the different outputs. The Figure 1-b shows a comparison between

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the detected signals measured by an optical fiber and an external detector on a chip without III-V processing and by the integrated photodiodes bonded on the output gratings couplers. A good correlation is found for the detected maximum, but a cross-talk related to the III-V process is observed for low photocurrents. Several solutions will be proposed to reduce the interactions between the different channels.

For the laser integration, a bonded GaSb laser was mechanically cleaved and electrically pumped. Different laser dimensions were compared. For the optimal dimensions (width of 20µm and length of 0.4mm), continuous wave operation at room temperature at 2.01µm wavelength is presented in Figure 2-a. Gain measurements were also performed showing low internal losses. These results confirm the very high potential of this technology for GaSb laser integration on a silicon waveguide circuit at 2.2µm. To finish, the different possibilities to couple light into the Si waveguide and to obtain single mode emission from these heterogeneously integrated lasers will be presented to reach the complete laser integration presented in Figure 2-b.

In conclusion, GaInAsSb photodiodes and GaSb-based lasers are currently the best candidates for integration in the short-wave infrared. These results allow to seriously envision a fully integrated spectrometer for sensing applications.

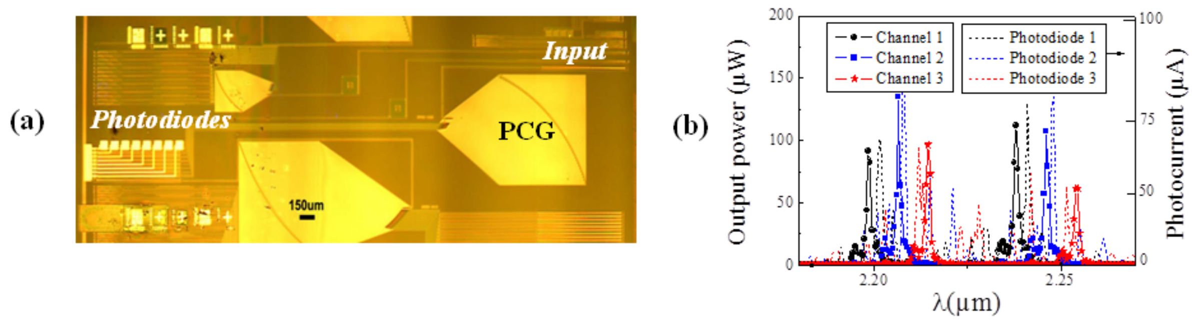


**Figure 1:** (a) Top view of a PCG spectrometer with integrated photodiodes processed at the outputs; (b) Comparison of the detected signal with and without photodiodes

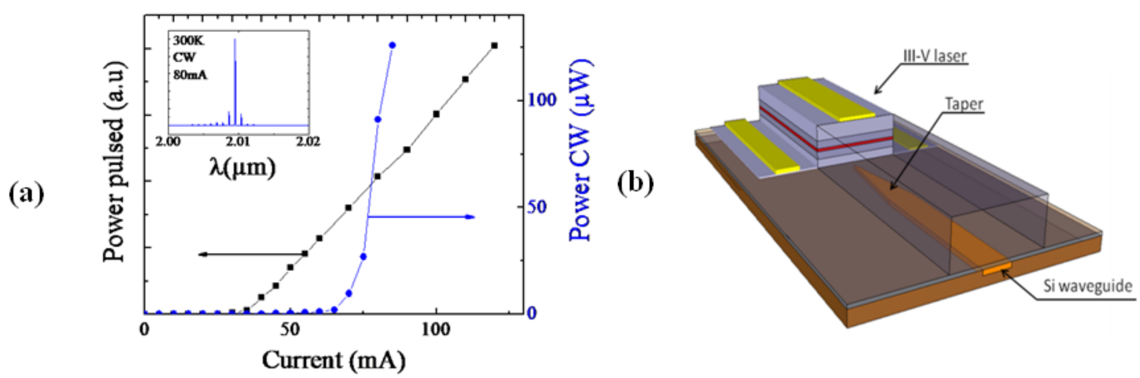


**Figure 2:** (a) measured spectrum and optical power versus current for a bonded GaSb laser; (b) design of the complete laser integration by a taper coupling system.

[1 ] N. Hattasan "Heterogeneous integration of GaInAsSb p-i-n photodiodes on a silicon-on-insulator waveguide circuit", IEEE Photonics Technology Letters, 23(2011), p.1760 (2011)

[2 ] A. Gassenq "Study of evanescently-coupled and grating-assisted GaInAsSb photodiodes integrated on a silicon photonic chip" *submitted to Optics Express*

[3] E. Ryckeboer, "Integrated spectrometer and integrated detectors on Silicon-on-Insulator for short-wave infrared applications", accepted for oral in CLEO 2012

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