Transfer-print integration of GaAs p-i-n photodiodes onto silicon nitride photonic integrated circuits

Jeroen Goyvaerts
Ghent University - imec
Ghent, Belgium
jeroen.goyvaerts@ugent.be

Sulakshna Kumari
Ghent University - imec
Ghent, Belgium
sulakshna.kumari@ugent.be

Sarah Uvin
Ghent University - imec
Ghent, Belgium
sarah.uvin@ugent.be

Jing Zhang
Ghent University - imec
Ghent, Belgium
jingzhan.zhang@ugent.be

Roel Baets
Ghent University - imec
Ghent, Belgium
roel.baets@ugent.be

Agnieszka Gocalinska
Tyndall National Institute
Cork, Ireland
agnieszka.gocalinska@tyndall.ie

Emanuele Pelucchi
Tyndall National Institute
Cork, Ireland
emanuele.pelucchi@tyndall.ie

Brian Corbett
Tyndall National Institute
Cork, Ireland
brian.corbett@tyndall.ie

Günther Roelkens
Ghent University - imec
Ghent, Belgium
gunther.roelkens@ugent.be

***Abstract*—We demonstrate the integration of GaAs p-i-n photodiodes onto silicon nitride grating couplers by means of transfer-printing. Dark currents below 20 pA and waveguide-coupled responsivities of 0.30 A/W are obtained. The detectors are integrated with an on-chip near-infrared spectrometer.**

Keywords—Transfer-printing, GaAs, photodiode, p-i-n, AWG

I. Introduction

Over the last few years, the field of silicon nitride SiN_x photonics has gained significant momentum [1]. As such, academic and commercial interest has been growing in Europe. There are several commercially available SiN_x MPW offerings, such as those from Lionix, Ligentec, imec and CSIC-CNM. Most of those platforms offer some additional functionality in the form of thermal phase shifters. Recently, Lionix even demonstrated the co-integration of an InP gain chip for 1550 nm through butt-coupling [2]. However, a lack of integrated light sources and detectors remains an issue for wavelengths other than the telecom region. There are several approaches of hybrid integration to address the integration of active components, such as flip-chipping, butt-coupling, wafer bonding, hetero-epitaxial growth and, more recently, micro-transfer-printing (µTP). As the current SiN_x market is still developing and the application demonstrators are still in the low volume range, the techniques of choice, so far, have been flip-chipping or butt-coupling of the active components. The downsides of those approaches are that they do not offer scaling towards high-volume production or towards the dense integration of active components, respectively. We believe that the heterogeneous integration by means of µTP, as illustrated in Fig. 1(a) is the best candidate to integrate III-V active components and other materials, and solve the aforementioned bottlenecks. With this technique, coupons are pre-fabricated on a source substrate, here p-i-n photodiodes (PDs) on a GaAs substrate as shown in Fig. 1(b). GaAs is the material of choice due to its relevance in the near-infrared, which covers applications in datacom links, photonic interposers and biosensing [3]. The key advantage that µTP brings to photodetector integration, is that it is a wafer-scale compatible process and thus easily scalable towards larger volumes by printing devices in a massively parallel fashion.

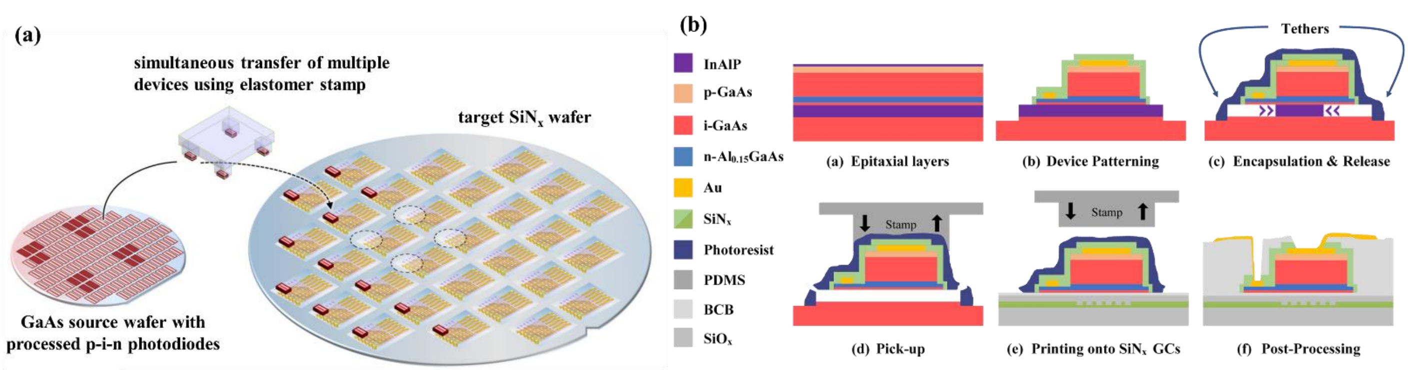

Fig. 1. Schematics of (a) micro- transfer printing on wafer-level scale and (b) the device fabrication and µTP process on a component level.

This work has been carried out in the context of the H2020 PIX4LIFE project, id 688519 and the ECSEL - EU project MICROPRINCE, id 737465.

II. Photodetector Design and Fabrication

The GaAs p-i-n photodetectors are designed to operate from 750 nm to 870 nm and are printed on top of SiN_x grating couplers (GCs), which are more alignment tolerant than a waveguide coupled approach. Earlier demonstrations of grating-assisted PDs have shown the relevance of this approach [4]. The light is diffracted upwards by the GC and through the transparent n-contact layer into the intrinsic GaAs absorption layer. At 2 µm, a sufficiently thick absorption layer is used to improve the responsivity. The devices are fabricated by defining a p-metal contact in a tetris block shape, which aides in the alignment procedure during printing. Next, the mesas are defined with dry-ICP etching. The n-contact layer is a $Al_{0.15}Ga_{0.85}As$ layer, transparent down to 760 nm. Afterwards, the release layer is patterned and etched down to reach the substrate. A photoresist encapsulation is used to anchor the PDs onto the substrate. A HCl-based etchant releases the devices by selectively etching the InAlP layer over the GaAs layers. After the release, the devices are picked up in a parallel manner by using a multi-post stamp. They are then printed onto the SiN_x GC circuits. The alignment is facilitated by the p-contact marker on the PD and the pattern recognition markers in the waveguide layer, next to the GCs. After printing, the devices are planarized with BCB, the contacts are opened and probe pads are deposited.

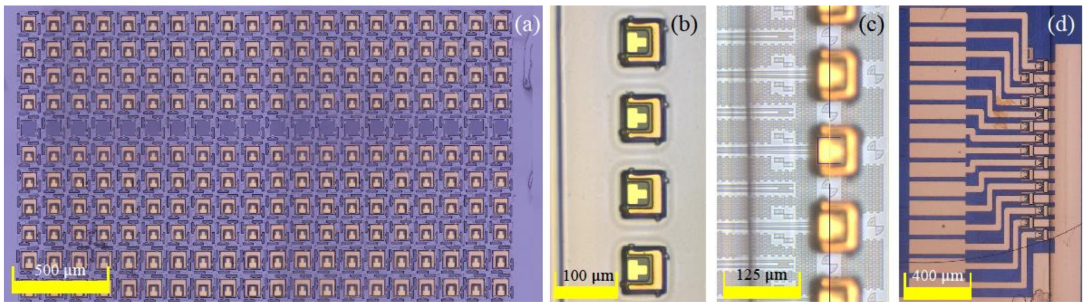

Fig. 2. Microscope images of (a) the source substrate with pre-processed PDs, (b) multi-PD pick-up on the PDMS stamp, (c) visual alignment and printing on top of the AWG channel output GCs and (d) the final interconnected system after post-processing (planarization, VIA access and metallization).

III. Results

Three photonic test circuits are designed: a PD reference test site around 780 nm, one around 850 nm and a demonstrator circuit with an arrayed waveguide grating (AWG) spectrometer at 780 nm. The PDs are characterized with a broadband Ti-Sapphire tunable laser. From 46 printed PDs, an averaged dark current of 11.48 pA is measured, (Std Dev 4.49 pA). The differential resistance is down to 44 Ohm. For the responsivity measurements, reference GCs structures were characterized to find the single GC insertion loss. By monitoring the laser output power through a fiber splitter, we determine the responsivity as shown in Fig.3 (a)-(b). The AWG-demonstrator has an optical cross-talk of 22 dB. The measured photocurrents clearly show that the cross-talk is not changed and thus prove the viability of the PD integration on more complex circuits.

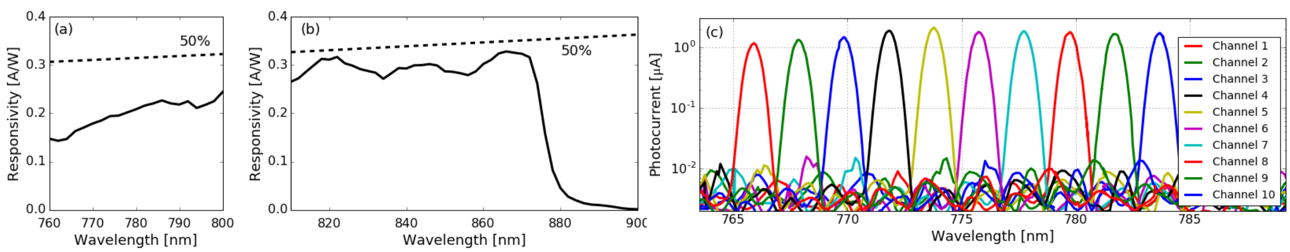

Fig. 3. The measured responsivity of the waveguide-coupled PD (a) from 760 nm to (b) 900 nm. (c) Shows the measured photocurrent of the AWG output PDs.

IV. Conclusions

We demonstrated the transfer-printing of GaAs p-i-n PDs on a SiN_x waveguide platform, with coupling enabled by GCs and showcased with an AWG spectrometer. The device characteristics are comparable with off-the shelf products, with dark currents in the 15 pA range and responsivity at 0.2-0.3 A/W. The benefit of our µTP is twofold: large volume-wafer scale compatibility and cost reduction due to the reduced footprint of these devices compared to flip-chip products.

References

[1] P. Muñoz et al., "Silicon nitride photonic integration platforms for visible, near-infrared and mid-infrared applications,"Sensors (Switzerland), vol. 17, no. 9, pp. 1–25, 2017.

[2] Y. Fan et al., "Optically integrated InP-Si_3N_4 hybrid laser," IEEE Photonics Journal, vol. 8, no. 6, 2016

[3] D. Martens et al., "A low-cost integrated biosensing platform based on SiN nanophotonics for biomarker detection in urine," Analytical Methods, vol. 10, no. 25, pp. 3066–3073, 2018

[4] J. Zhang et al., "Silicon photonics fiber-to-the-home transceiver array based on transfer-printing-based integration of III-V photodetectors," Optics Express, vol. 25, no. 13, p. 14290, 2017.