



HAL
open science

Filling the gap of silicon nitride photonic platform functionalities using micro-transfer printing

Maximilien Billet, Tom Vanackere, Tom Vandekerckhove, Margot Niels, Luis Reis, Dennis Maes, Max Kiewiet, Konstantinos Akritidis, Stijn Cuyvers, Stijn Poelman, et al.

► To cite this version:

Maximilien Billet, Tom Vanackere, Tom Vandekerckhove, Margot Niels, Luis Reis, et al.. Filling the gap of silicon nitride photonic platform functionalities using micro-transfer printing. Integrated Photonics Research, Silicon and Nanophotonics, 2023, Busan, South Korea. pp.ITu2A.2, 10.1364/IPRSN.2023.ITu2A.2 . hal-04578610

HAL Id: hal-04578610

<https://hal.science/hal-04578610v1>

Submitted on 17 May 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

Filling the gap of silicon nitride photonic platform functionalities using micro-transfer printing

Maximilien Billet¹, Tom Vanackere^{1,2}, Tom Vandekerckhove^{1,2}, Margot Niels¹, Luis Reis^{1,2}, Dennis Maes^{1,3}, Max Kiewiet¹, Konstantinos Akritidis¹, Stijn Cuyvers¹, Stijn Poelman¹, Tom Reep¹, Valeria Bonito Oliva¹, Francois Leo², Gunther Roelkens¹ and Bart Kuyken¹

¹Photonics Research Group, INTEC, Ghent University - imec, Ghent, Belgium

²OPERA-Photonique, Université Libre de Bruxelles, Bruxelles, Belgium

³Institut d'Electronique de Microélectronique et de Nanotechnologie, CNRS-UMR 8520, Villeneuve d'Ascq, France

Abstract: In this work we demonstrate the heterogeneous integration of active devices on the SiN photonic platform using micro-transfer printing and we will discuss the remaining technological challenges

Photonic integrated circuits enable the miniaturization of key optical functions. Silicon (Si) and silicon nitride (SiN) photonic platforms have proven their maturity based on their compatibility with CMOS technology, giving rise to low cost, compact and scalable optical systems on a chip. Furthermore, in the case of SiN, the wide transparency window extends across the visible and near-infrared spectral regions, making it a strong candidate for numerous applications, including telecom/datacom, quantum technologies and bio-sensing. However, the SiN photonic platform lacks some important functionalities such as optical amplification, modulation, photodetection and intrinsic second order nonlinear frequency conversion. A versatile solution is to heterogeneously integrate devices, based on different materials, using the technique of micro-transfer printing [1] (Fig. 1). As such, diverse functionalities can be added to the SiN photonic platform at the back-end level to retain CMOS compatibility. In this presentation, we will discuss the remaining technological challenges such as SiN-to-device light coupling, wavelength compatibility, post-integration processing, limit of printed device sizes, multiple hetero-integration and scalability. Several recent device demonstrations (tab 1) are discussed to exemplify the current state-of-the-art and challenges.

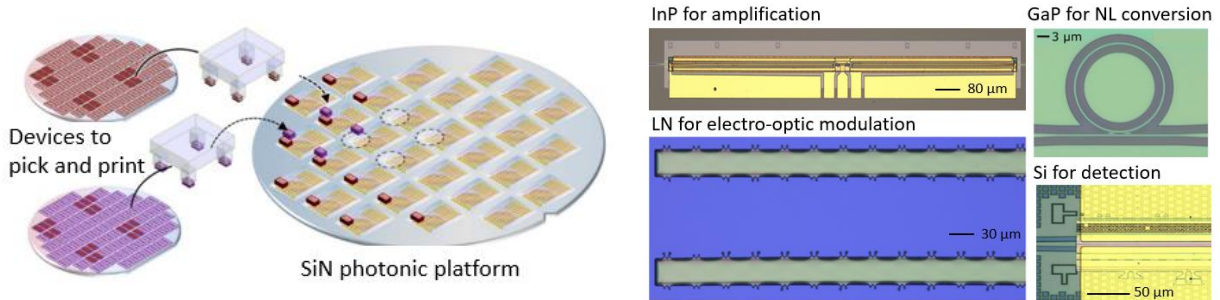


Fig. 1. Illustration of devices hetero-integration on a SiN wafer via micro-transfer printing and microscope pictures of transfer printed devices

Table 1. Overview of the silicon nitride photonic platform properties and examples of micro-transfer printed devices adding new functionalities on the platform

Property / functionality	SiN	Possible micro-transfer printed devices
Transparency window	0.25 to 5 μm	-
Propagation losses	0.01 to 0.1 dB/cm	-
Two-photon absorption	Negligible	-
Industry status	Low-volume production	-
Optical gain	Absent	InGaAs [2] / GaAs [3] / GaN [4] based amplifiers
Fast modulation	No Pockels, no carriers	Lithium niobate (LN) electro-optic modulators [5]
Nonlinear conversion	no intrinsic $\chi^{(2)}$, $\chi^{(3)}$	PPLN [6] / GaP [7] ($\chi^{(2)}$ and $\chi^{(3)}$) waveguides
Photodetection	No carriers	pin-Si photodiodes (slow) [8] / InGaAs UTC-photodiodes (fast) [9]

3. References

- [1] G. Roelkens et al., Micro-transfer printing for heterogeneous Si photonic integrated circuits, *IEEE Journal on Selected Topics in Quantum Electronics*, 2022
- [2] S. Cuyvers, B. Haq, C. Op de Beeck, S. Poelman, A. Hermans, Z. Wang, A. Gocalinska, M. Ellamei, B. Corbett, G. Roelkens, K. Van Gasse, B. Kuyken, Low Noise Heterogeneous III-V-on-Silicon-Nitride Mode-Locked Comb Laser, *Laser & Photonics Reviews*, 2021
- [3] M. Kiewiet, S. Cuyvers, A. Hermans, M. Billet, J. Zhang, G. Roelkens, K. Van Gasse, B. Kuyken, Scalable Heterogeneous Integration of a Pre-Processed Facet-Emitting Visible-Wavelength GaAs Laser, accepted for publication in *Conference on Lasers and Electro-Optics*, United States, (to be published) 2023.
- [4] S. Poelman, M. Billet, A. Hermans, N. Fiuczek, H. Turski, B. Kuyken, Transfer Printing of InGaN/GaN Quantum-Well based Light Emitting Diodes, accepted for publication in *Conference on Lasers and Electro-Optics*, United States, (to be published) 2023.
- [5] T. Vanackere, T. Vandekerckhove, L. Bogaert, M. Billet, S. Poelman, S. Cuyvers, Joris Van Kerrebrouck, Arno Moerman, Olivier Caytan, Sam Lemey, Guy Torfs, G. Roelkens, S. Clemmen, B. Kuyken, High-Speed Lithium Niobate Modulator on Silicon Nitride using Micro-Transfer Printing, accepted for publication in *Conference on Lasers and Electro-Optics*, United States, (to be published) 2023
- [6] T. Vandekerckhove, T. Vanackere, J. De Witte, I. Luntadila Lufungula, E. Vissers, G. Roelkens, S. Clemmen, B. Kuyken, High-Efficiency Second Harmonic Generation in Heterogeneously-Integrated Periodically-Poled Lithium Niobate on Silicon Nitride, accepted for publication in *Conference on Lasers and Electro-Optics Europe*, Germany, (to be published) 2023
- [7] M. Billet, L.N Reis, Y. Leger, C. Cornet, F. Raineri, I. Sagnes, K. Pantzas, G. Beaudoin, G. Roelkens, F. Leo, B. Kuyken, Gallium phosphide-on-insulator integrated photonic structures fabricated using micro-transfer printing, *Optical Materials Express*, 2021
- [8] S. Cuyvers, A. Hermans, M. Kiewiet, J. Goyvaerts, G. Roelkens, K. Van Gasse, D. Van Thourhout, B. Kuyken, Heterogeneous integration of Si photodiodes on silicon nitride for near-visible light detection, *Optics Letters*, 2022
- [9] D. Maes, S. Lemey, G. Roelkens, M. Zaknoute, V. Avramovic, E. Okada, P. Szriftgiser, E. Peytavit, G. Ducournau, B. Kuyken, High-speed uni-traveling-carrier photodiodes on silicon nitride, *APL Photonics*, 2023