Photonics Research Group / Ghent university / imec

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

JNIL 2023

Maximilien Billet, Tom Vanackere, Tom Vandekerckhove, Margot Niels, Luis Reis, Dennis Maes, Max Kiewiet, Konstantinos Akritidis, Stijn Cuyvers, Stijn Poelman, Tom Reep, Valeria Bonito Oliva, Francois Leo*, Gunther Roelkens and Bart Kuyken

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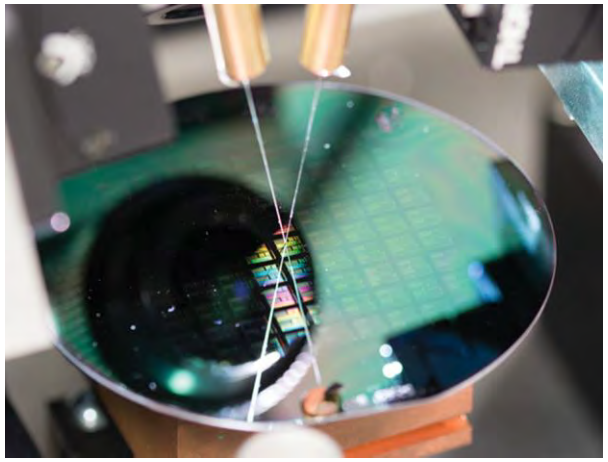
Contents

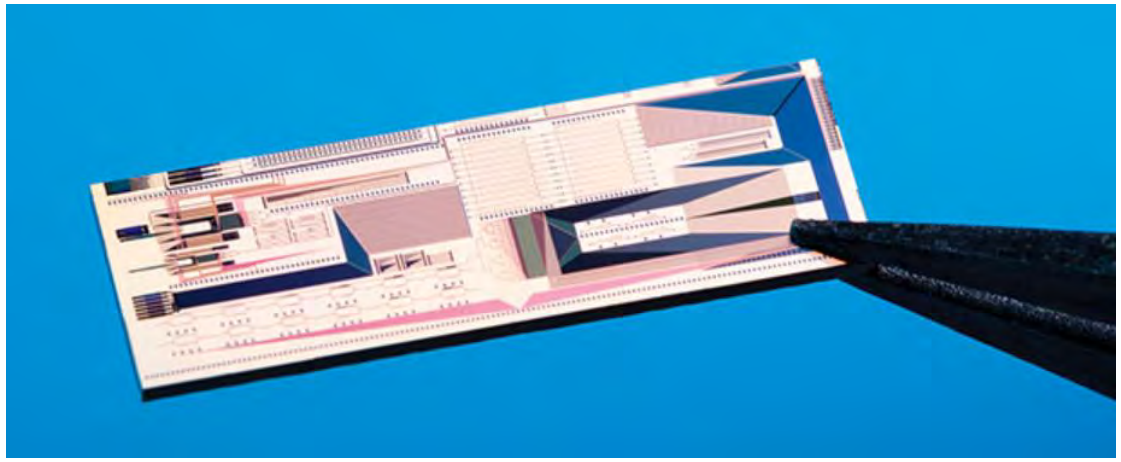
- **Presentation of the silicon nitride platform**
- Heterogeneous integration via micro-transfer printing
- Challenges related to the processing
- Results highlighting

Presentation of the silicon nitride platform

- **Integrated photonics using CMOS technology**



Source: Imec



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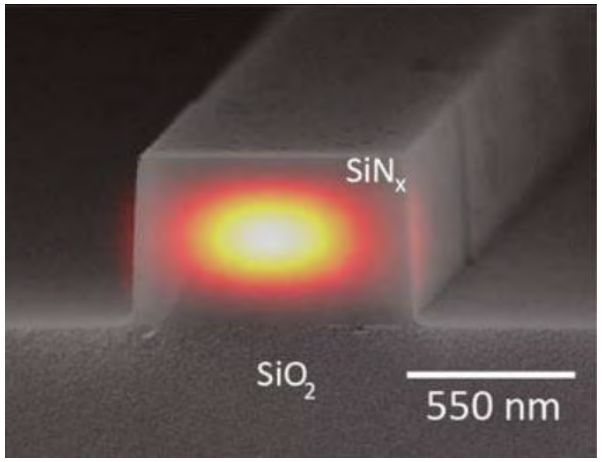


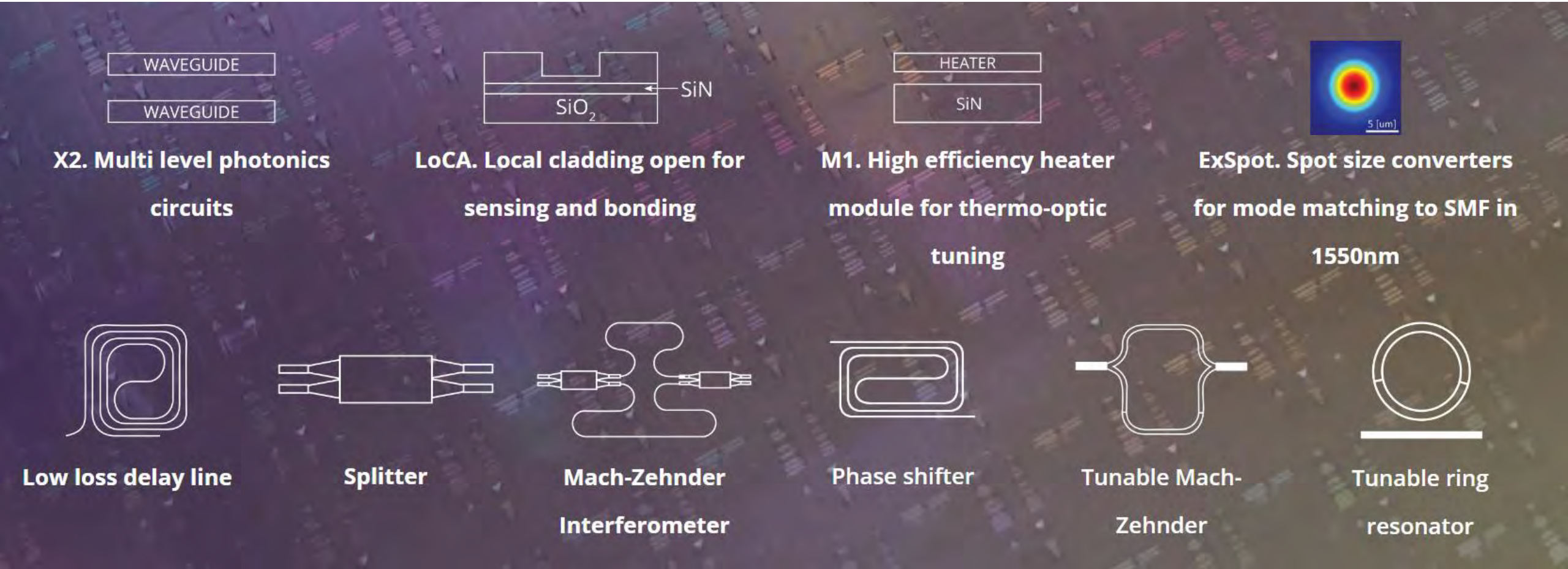
Source: CNST

Property / functionality	SiN
Transparency window	0.25 to 5 µm
Propagation losses	0.01 to 0.1 dB/cm
Two-photon absorption	Negligible
Industry status	middle-volume production (200 / 300 mm)
Optical gain	Absent
Fast modulation	No Pockels, no carriers
Nonlinear conversion	no intrinsic $\chi^{(2)}$, $\chi^{(3)}$
Detection	No carriers

Presentation of the silicon nitride platform

- **A robust and reliable platform for passive components**

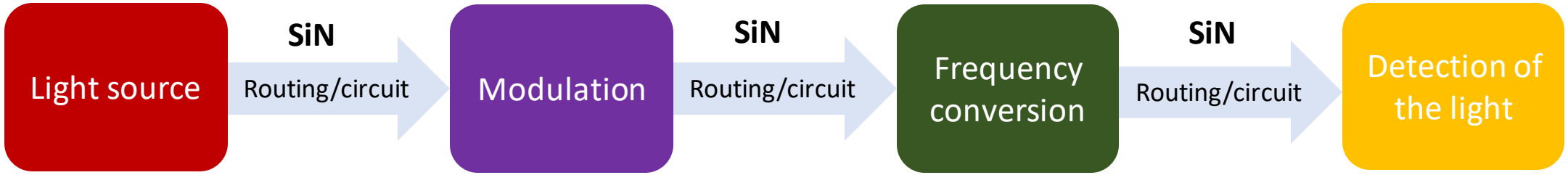
Ligentec website / passive components / process design kit available (MPW)



Presentation of the silicon nitride platform

- **But lacking several functionalities to push integrated photonics forward complex systems**

Generic view of a full system in integrated photonics



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Photodetection	No carriers

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- **Heterogeneous integration via micro-transfer printing**
- Challenges related to the processing
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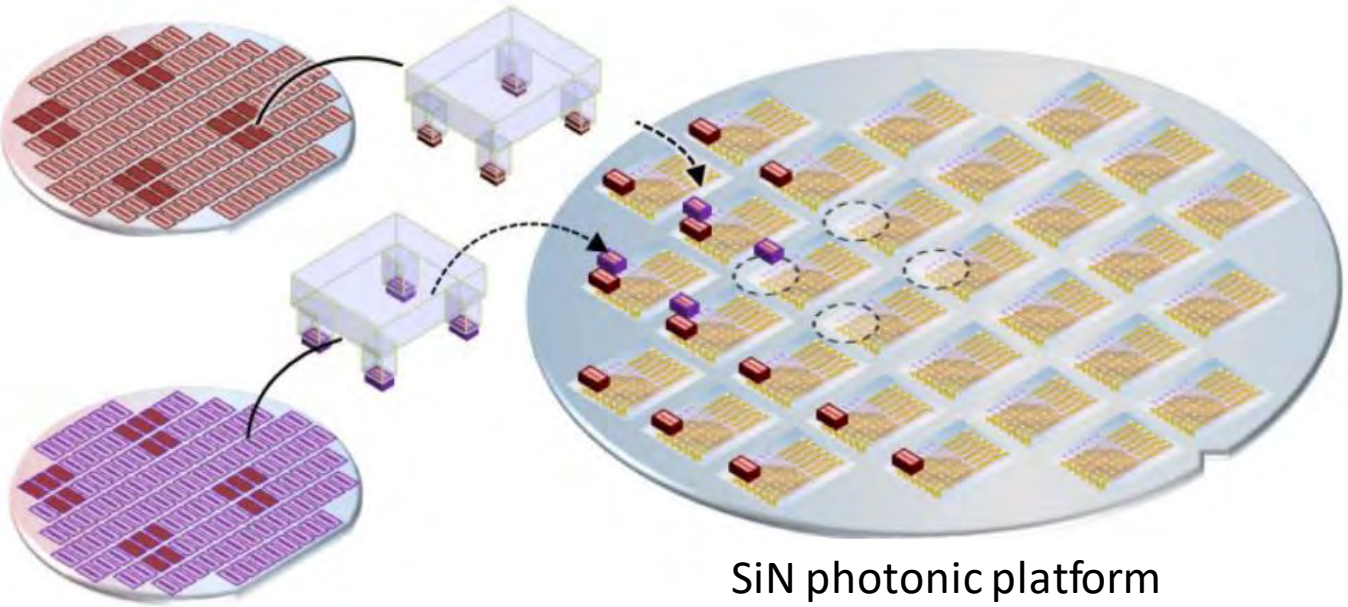
Heterogeneous integration via micro-transfer printing

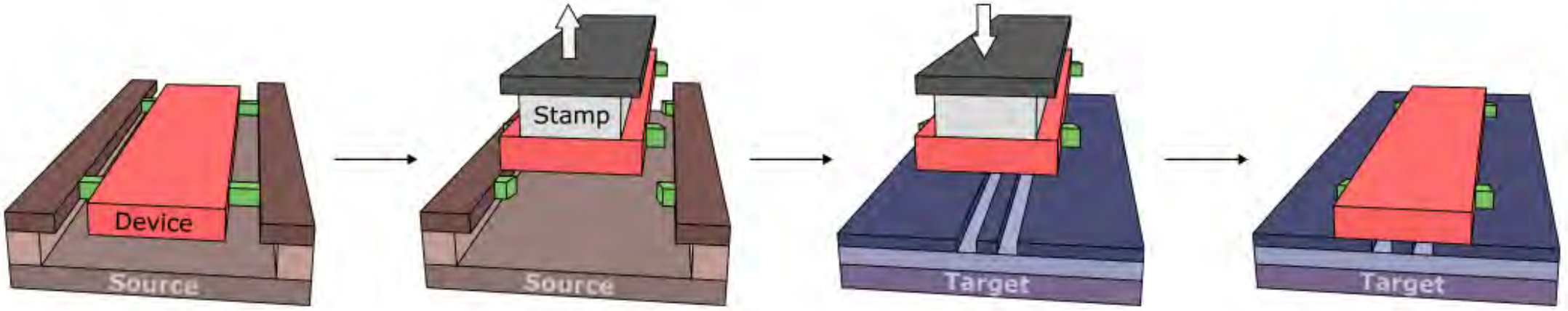
- **Using of micro-transfer printing as a versatile solution**



SiN photonic platform

Micro-transfer printing:

- High integration density
- Back-end compatible
- High efficiency of material use
- Alignment of 500 nm at 3σ
- High versatility for co-integration
- Low cost
- R&D maturity

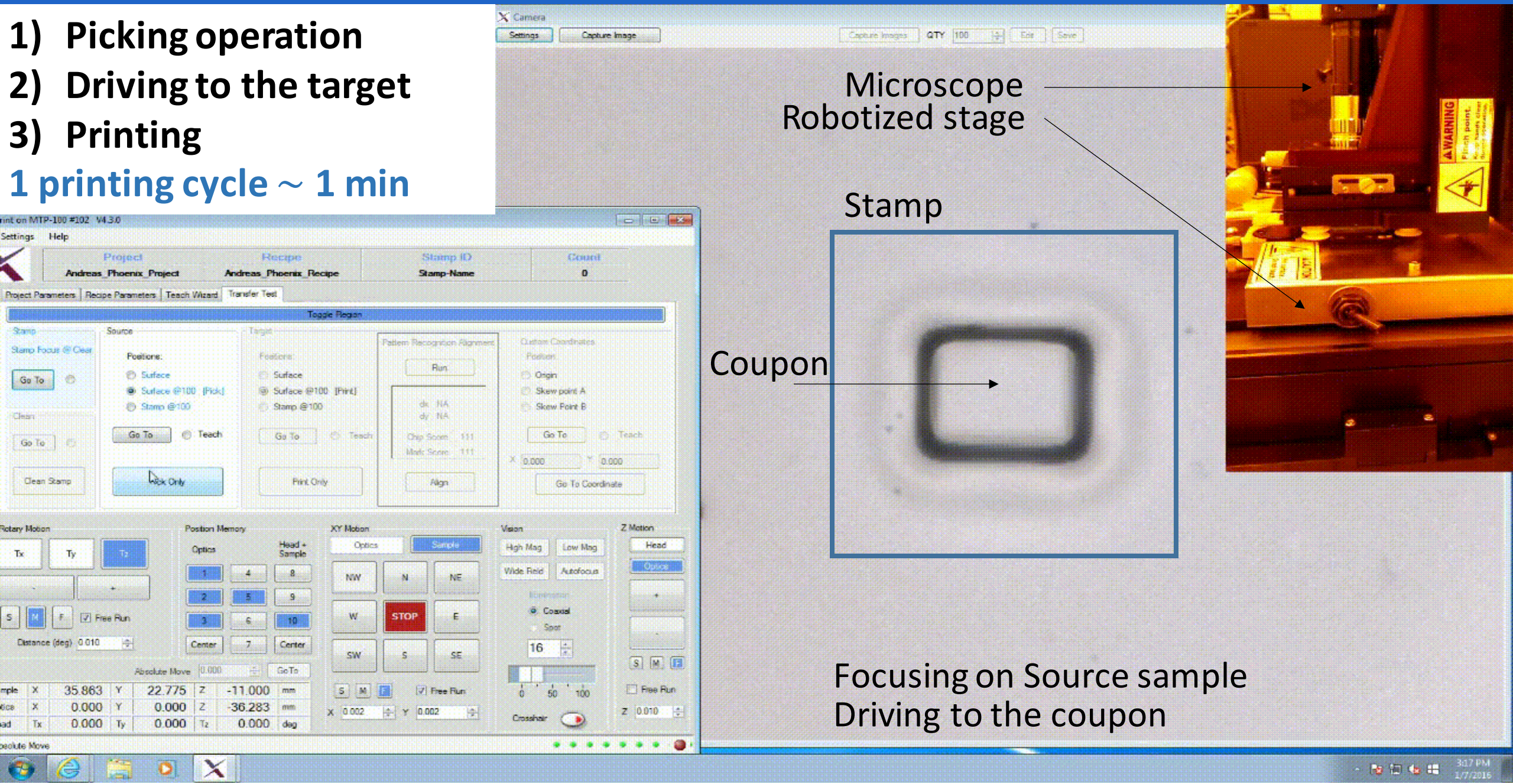


Pick-up Print

Heterogeneous integration via micro-transfer printing

1) **Picking operation**
2) **Driving to the target**
3) **Printing**

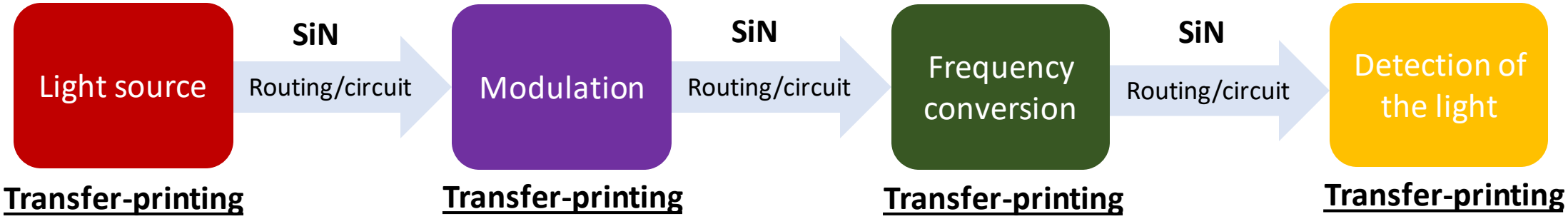
1 printing cycle ~ 1 min



Heterogeneous integration via micro-transfer printing

- **Possibility to populate the SiN platform with new functionalities**

Generic view of a full system in integrated photonics



Property / functionality	SiN	
Transparency window	0.25 to 5 µm	
Propagation losses	0.01 to 0.1 dB/cm	
Two-photon absorption	Negligible	
Industry status	middle-volume (200 / 300 mm)	
Optical gain	Absent	InGaAs / GaAs / GaN based amplifiers
Fast modulation	No Pockels, no carriers	LN electro-optic modulators
Nonlinear conversion	no intrinsic $\chi^{(2)}$, $\chi^{(3)}$	PPLN / GaP ($\chi^{(2)}$ and $\chi^{(3)}$) waveguides
Photodetection	No carriers	pin-Si photodiodes (slow) / InGaAs UTC-photodiodes (fast)

And many more results in the literature

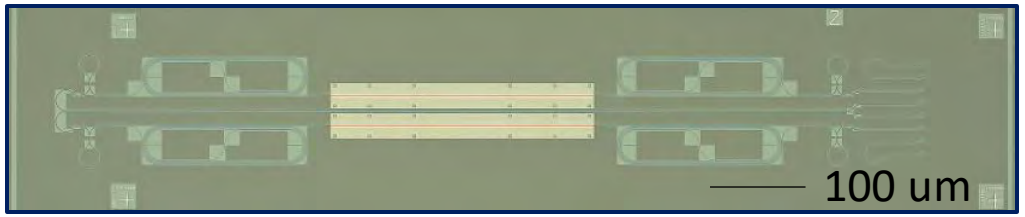
Contents

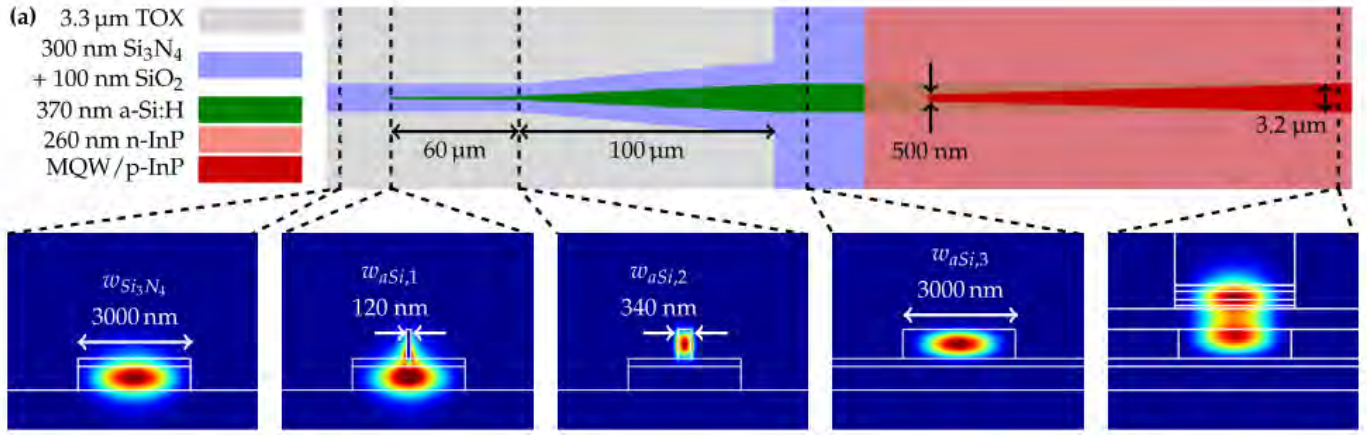
- Presentation of the silicon nitride platform
- Heterogeneous integration via micro-transfer printing
- **Challenges related to the processing**
- Results highlighting

Challenges related to the processing

- **Coupling from SiN to devices using <u>adiabatic tapers</u>**

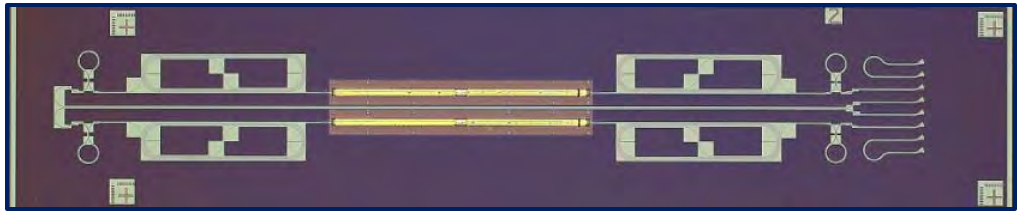
Passive SiN circuit



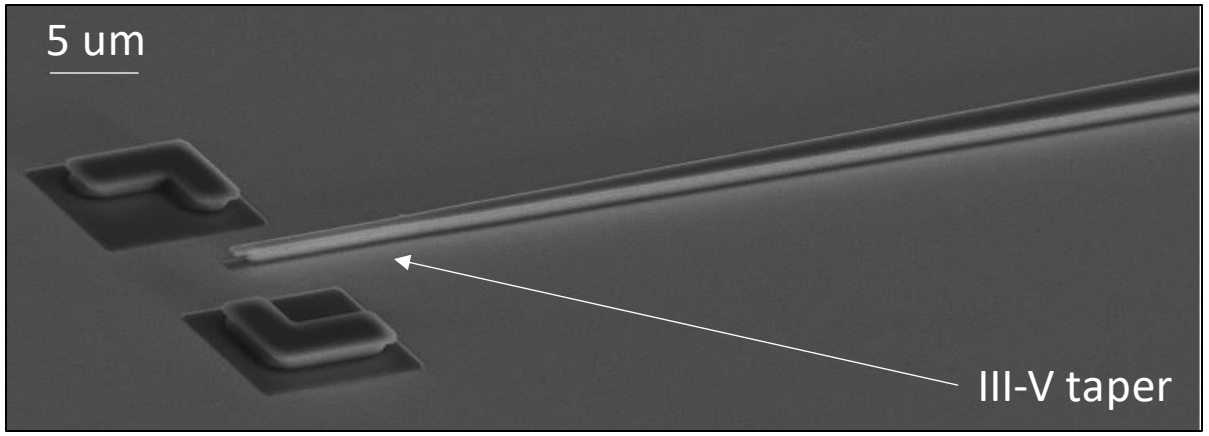


C. Op de Beck, et al. Heterogeneous III-V on silicon nitride amplifiers and lasers via microtransfer printing

Printing of III-V amplifiers



Etching of 500 nm wide x 2.5 um thick taper (III-V)



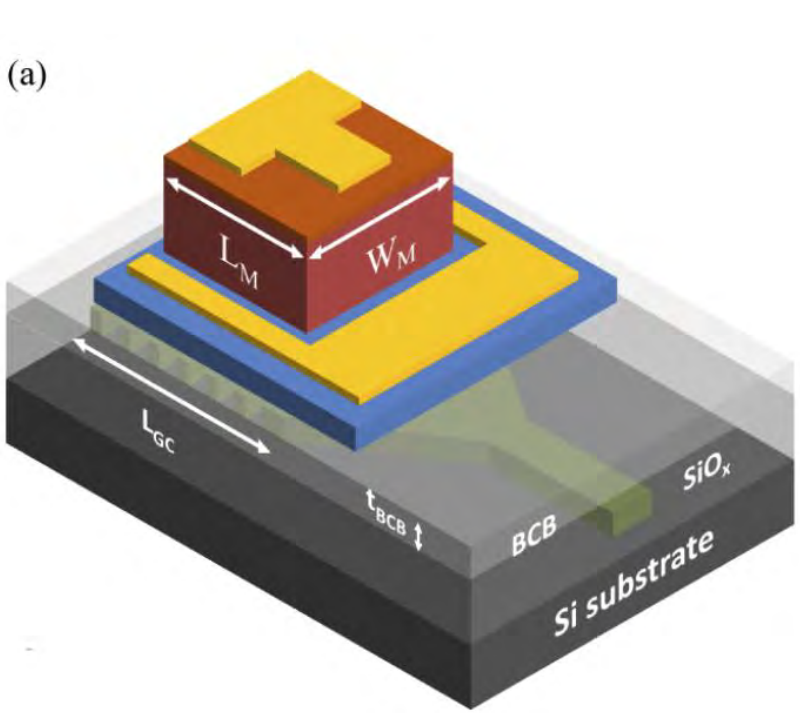
Challenges:

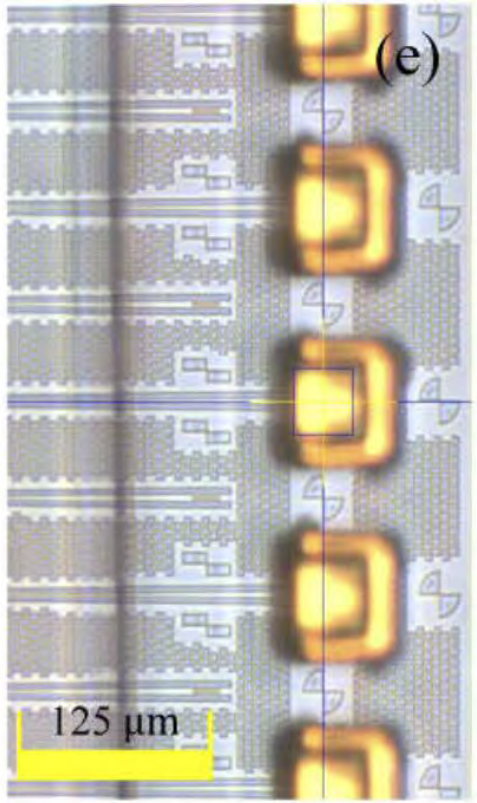
- **High aspect ratio etching / optical sidewall quality**
- **Intermediate aSi layer (custom platform) / aSi recipes depends on the Fab (index, stress…)**

Challenges related to the processing

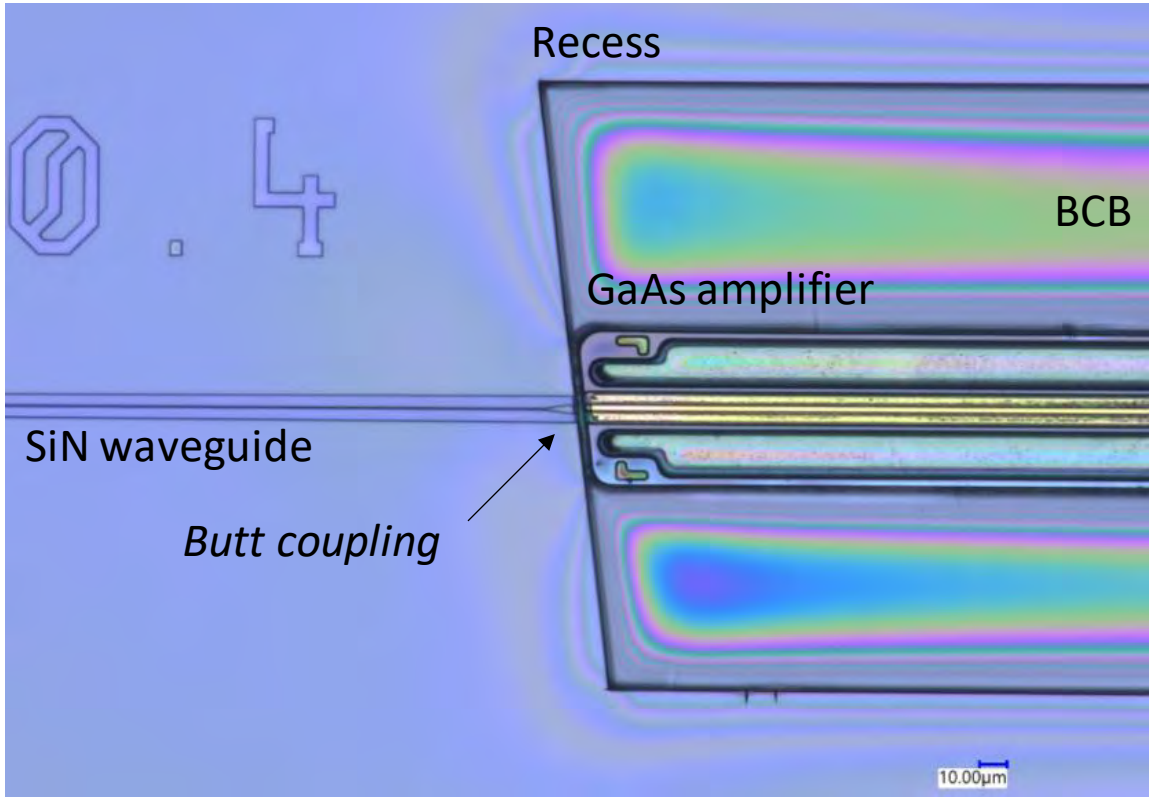
- **Coupling from SiN to devices using grating coupler / butt coupling**

Grating coupler assisted coupling





Direct butt coupling from the facet of the waveguide



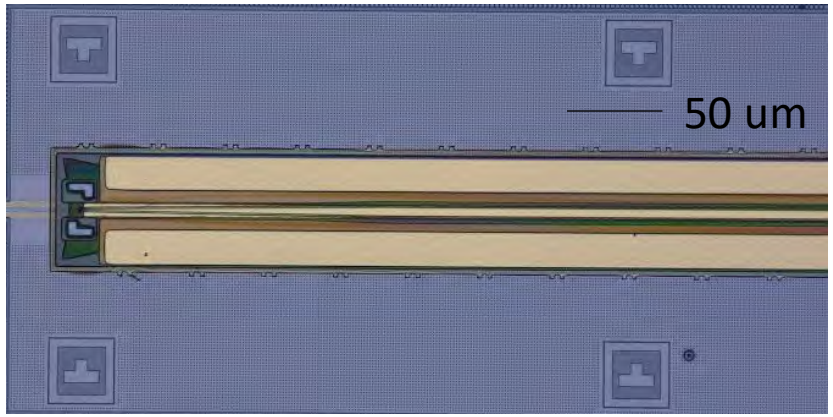
Challenges:

- **Printing alignment (1 um at UGent sample scale)**
- **Printing in a recess for butt coupling (BCB homogeneity / post processing)**

Challenges related to the processing

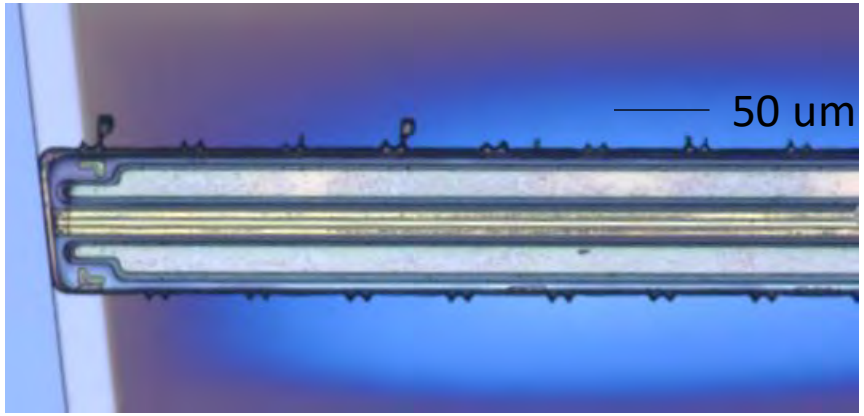
- **Wavelength compatibility**

InP based amplifiers (IR~1550 nm)

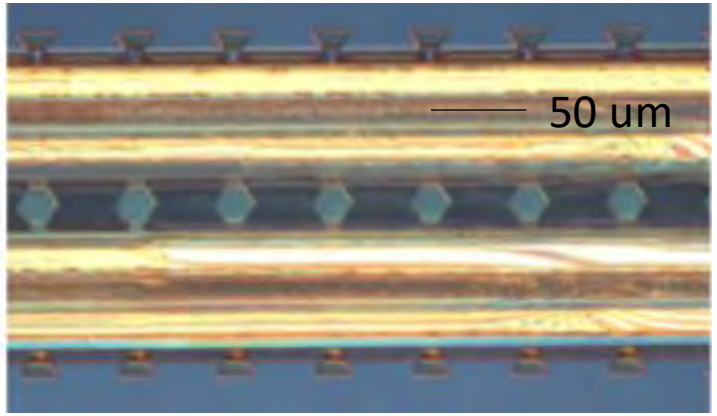


Typical coupon size 2 mm x 50 um

GaAs based amplifiers (NIR~800 nm)

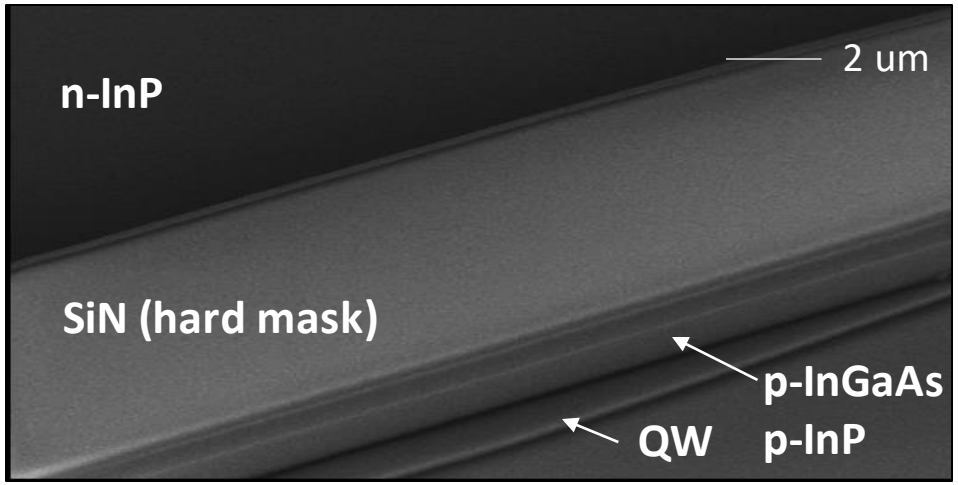


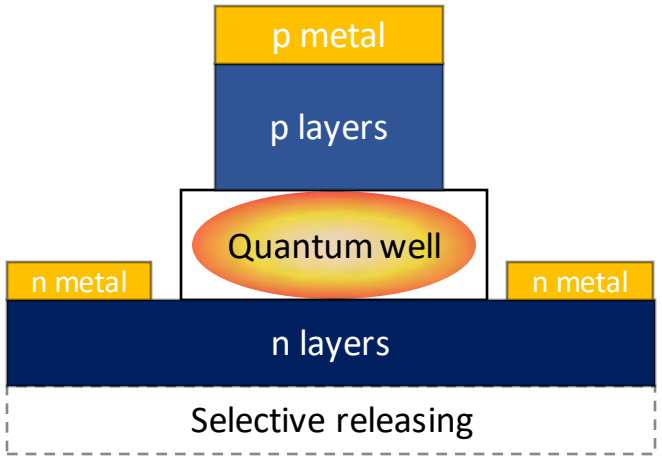
GaN based amplifiers (VIS~450 nm)



Challenges:

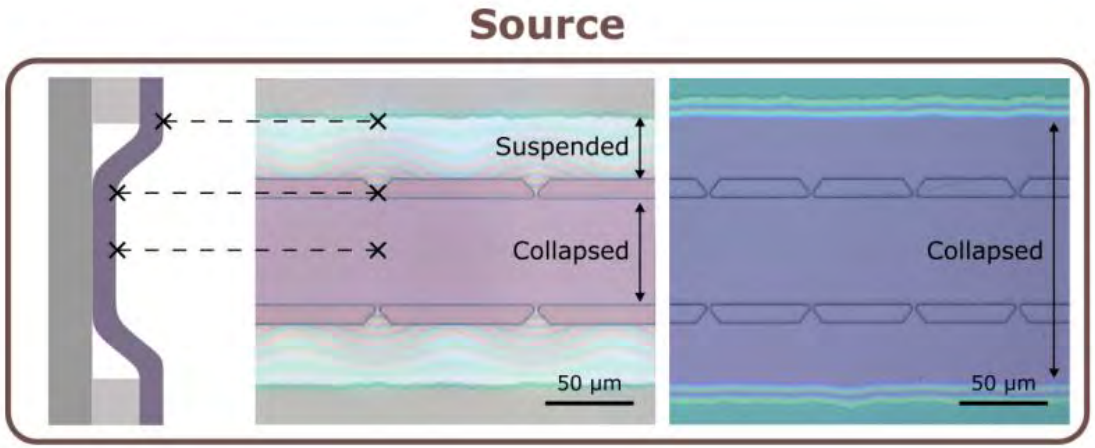
- **Full process flow for different III-V systems (Epitaxy / RIE / ICP / wet etching / releasing…)**

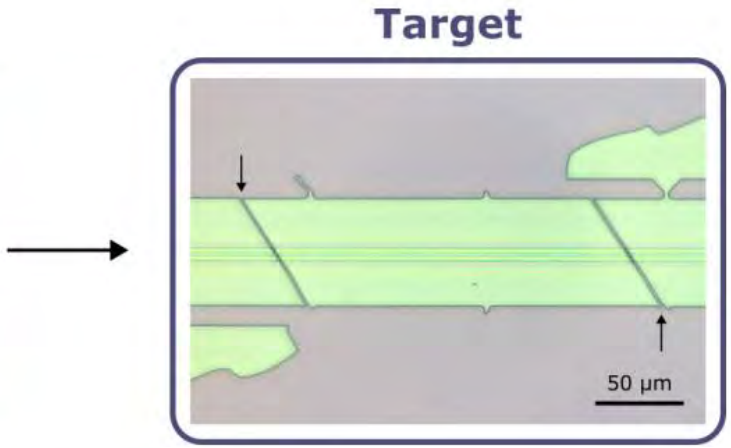


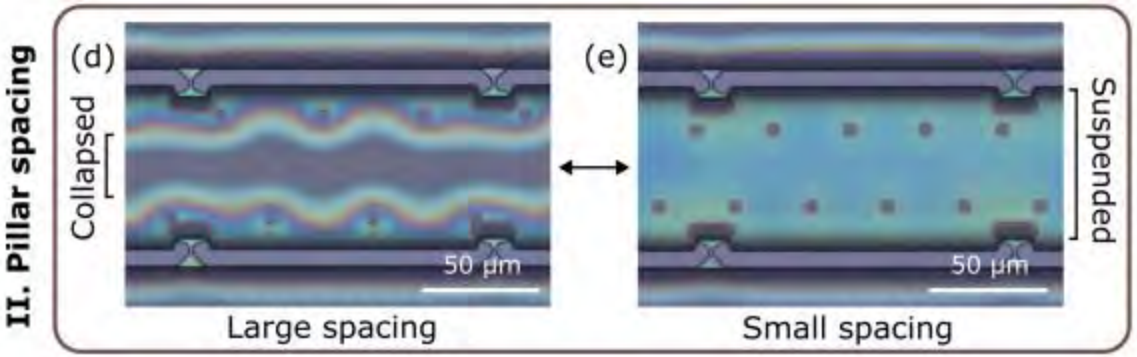


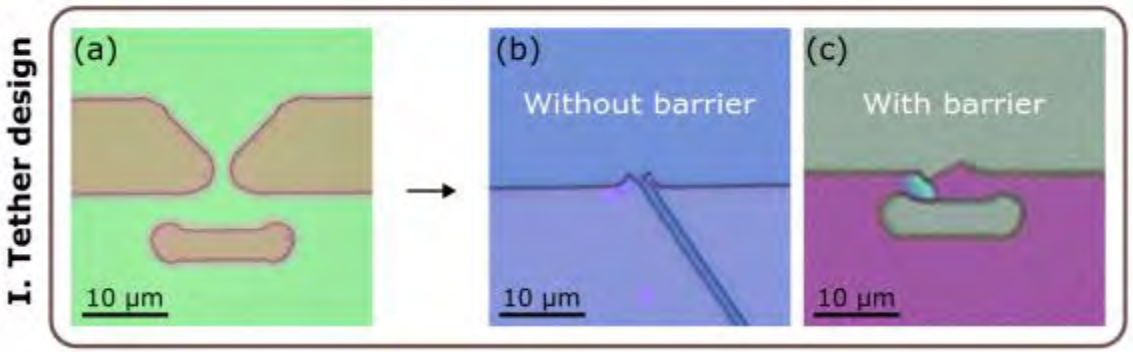
Challenges related to the processing

- **Releasing / picking / printing of the devices**



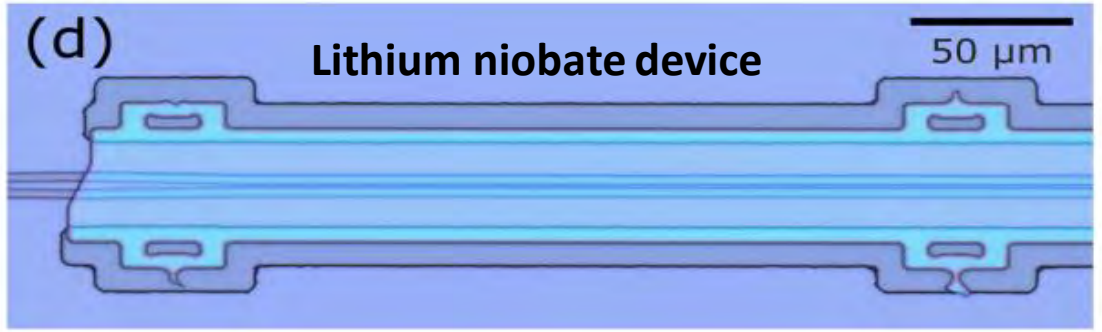






Challenges:

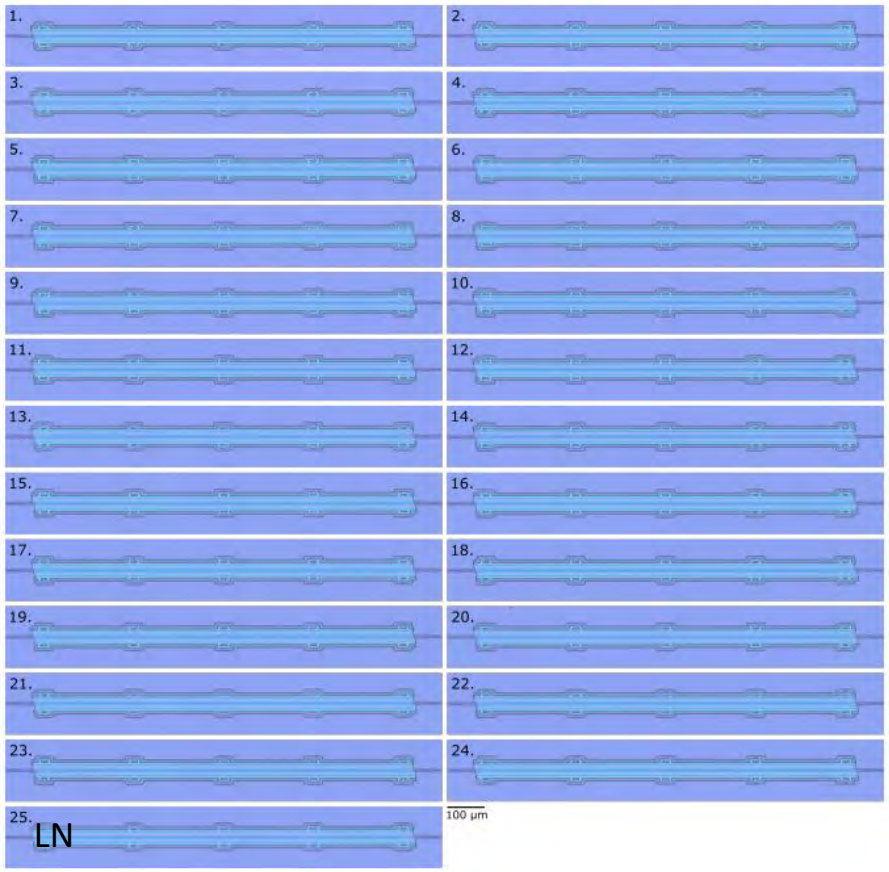
- **Advanced designs of coupon encapsulation (mechanical support)**
- **Advanced designs of tethers (easily breakable / strong enough / anti-crack barriers)**



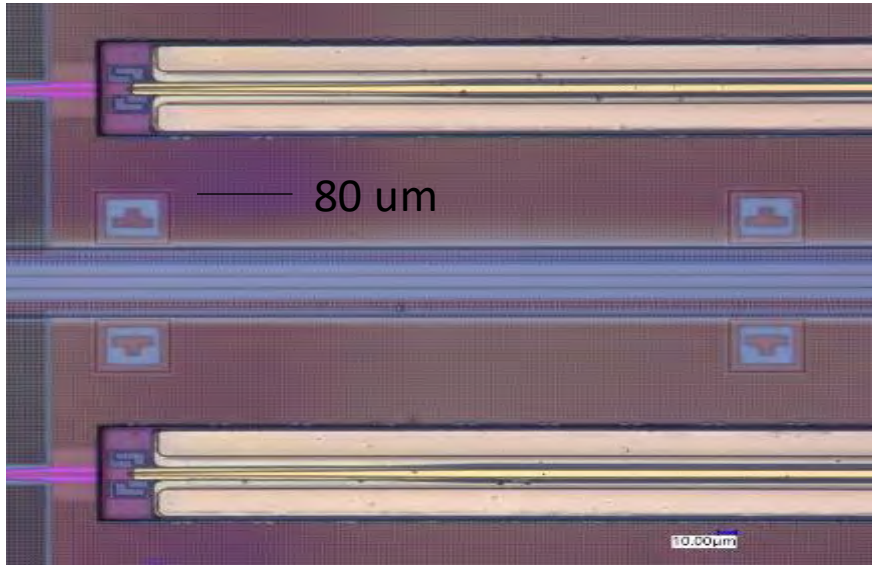
Challenges related to the processing

- **Scalability**

Example of 25 LN coupons printing (single)



Example of a 2 x 3 array printing of InP-SOAs



Example of a 1 cm long LN coupon printing

Challenges:

- **Yield of fabrication / picking / printing / wafer scale processing**
- **Printing of array / wafer scale printer / wafer scale alignment (500 nm)**
- **Size of the coupons (um to cm scale)**

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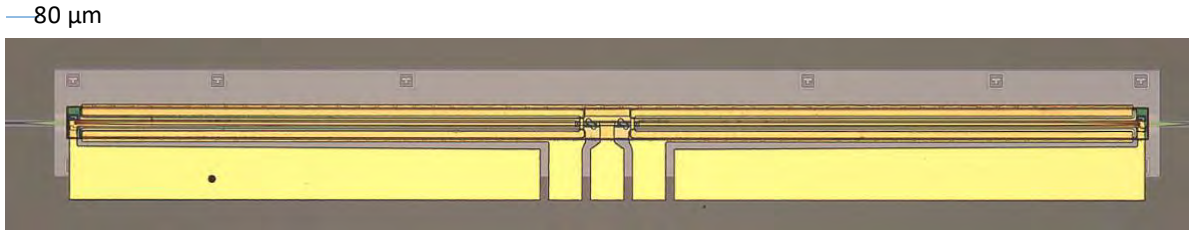
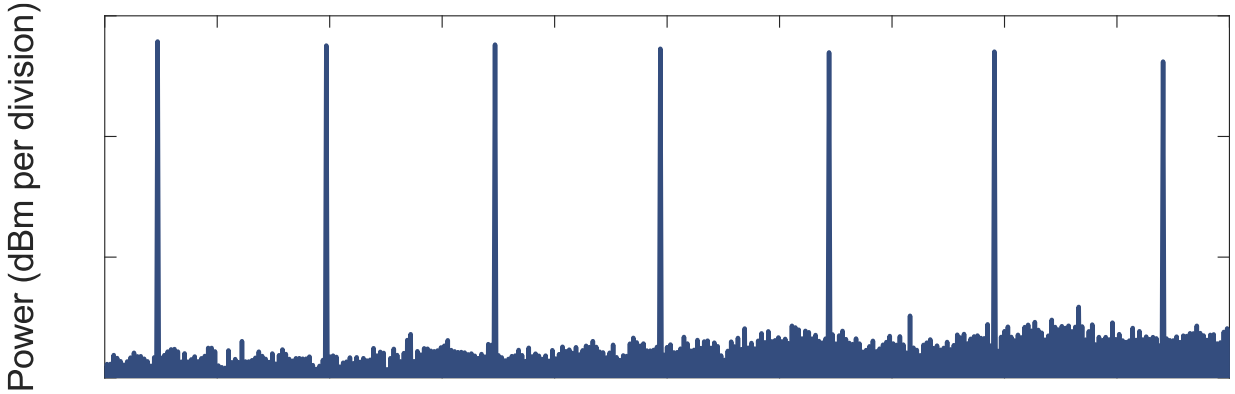
- **Results highlighting**

Results highlighting

- **SiN/InP mode-locked lasers for dual-comb applications**

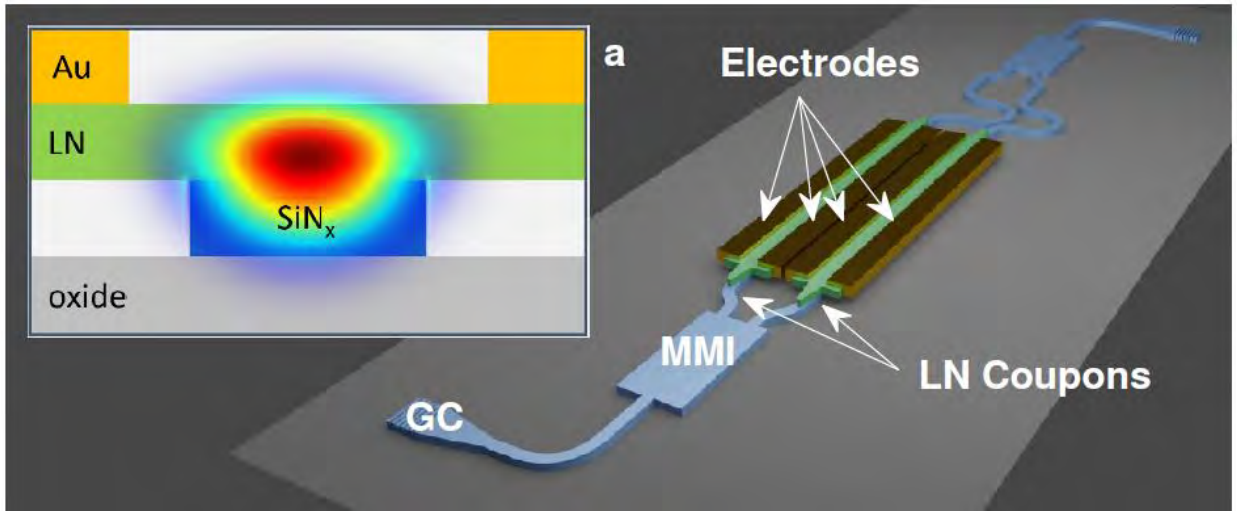


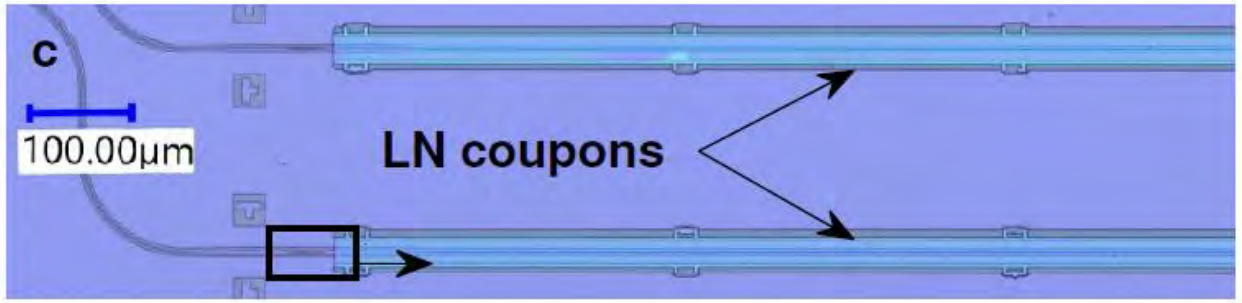
Repetition rate = 3 GHz

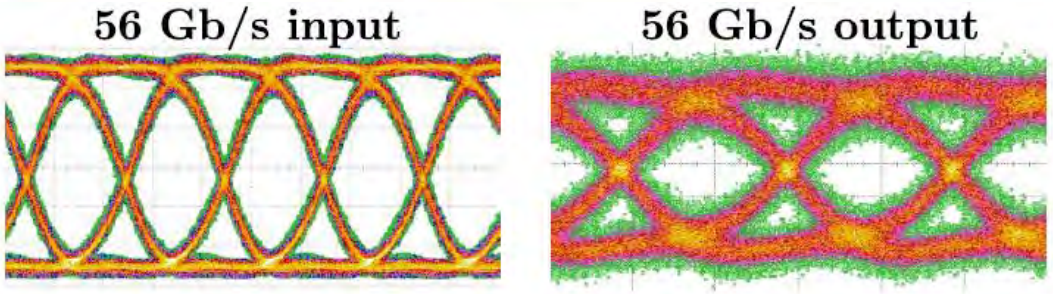


Results highlighting

- **SiN/LN for high speed modulation**



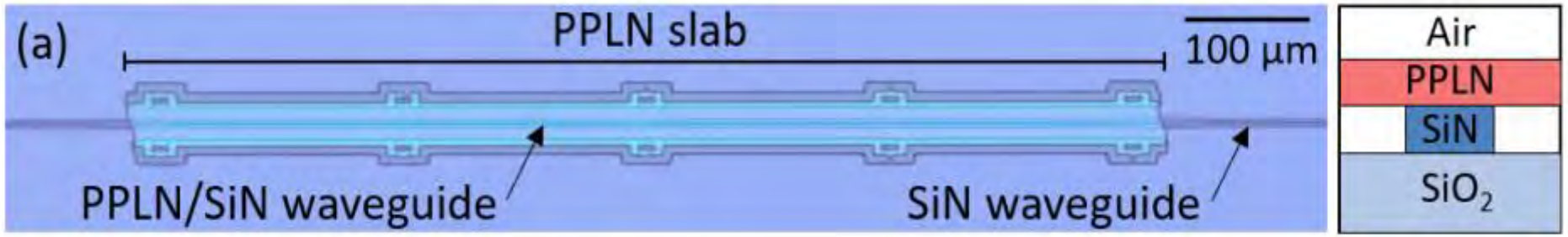


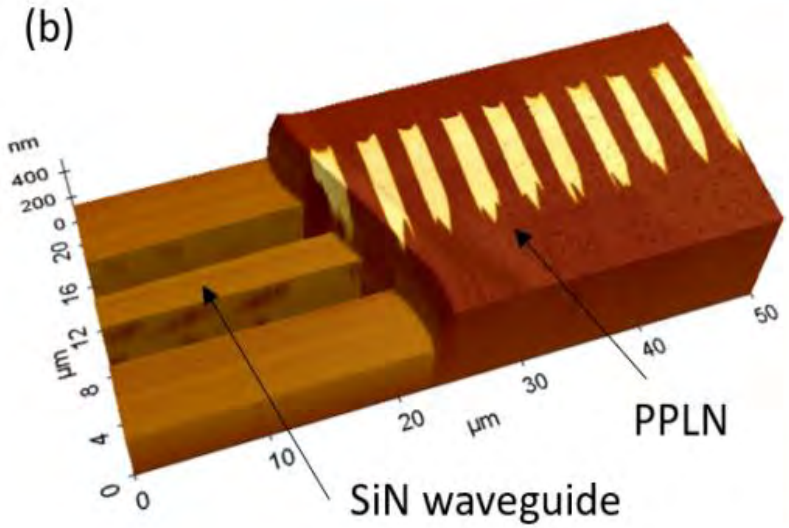


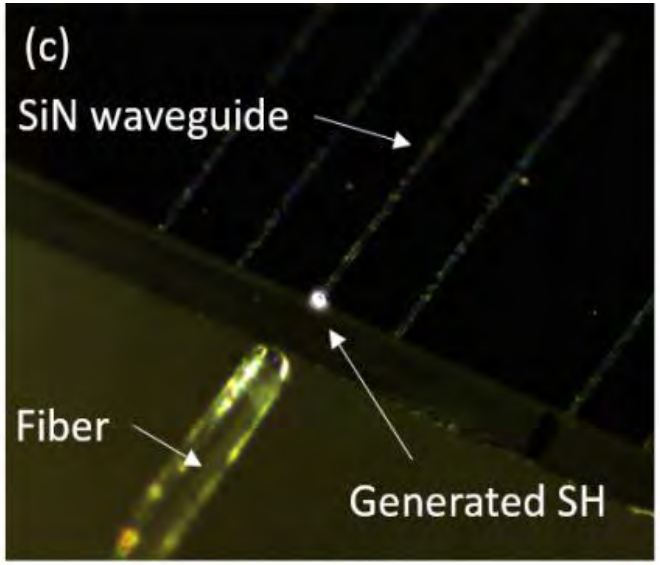
T. Vanackere et al, APL photonics/CLEO 2023

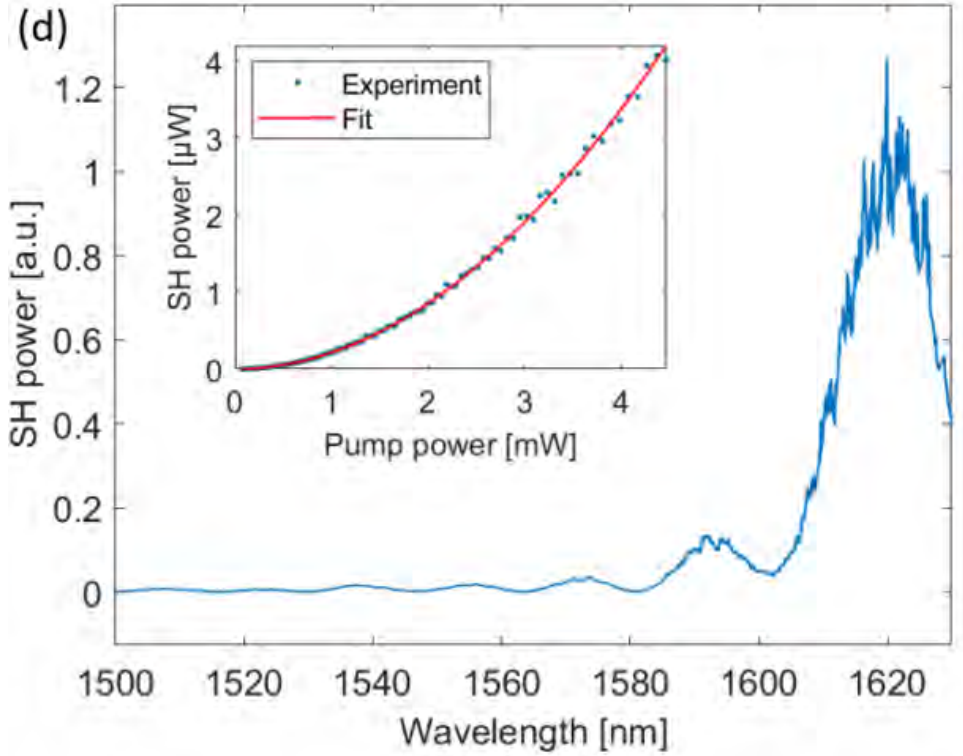
Results highlighting

- **SiN/PPLN for second harmonic generation**





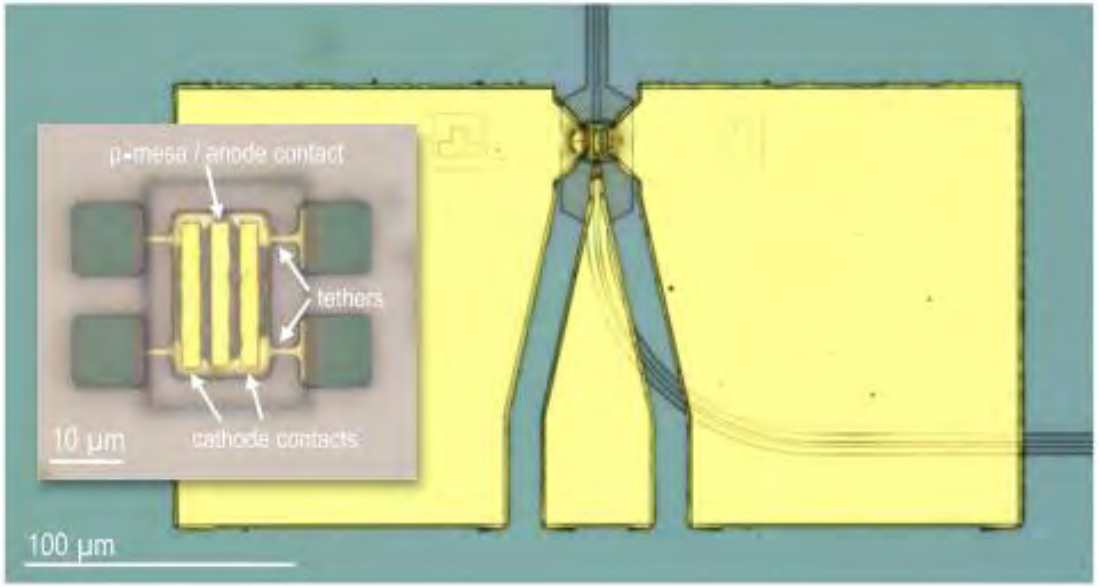


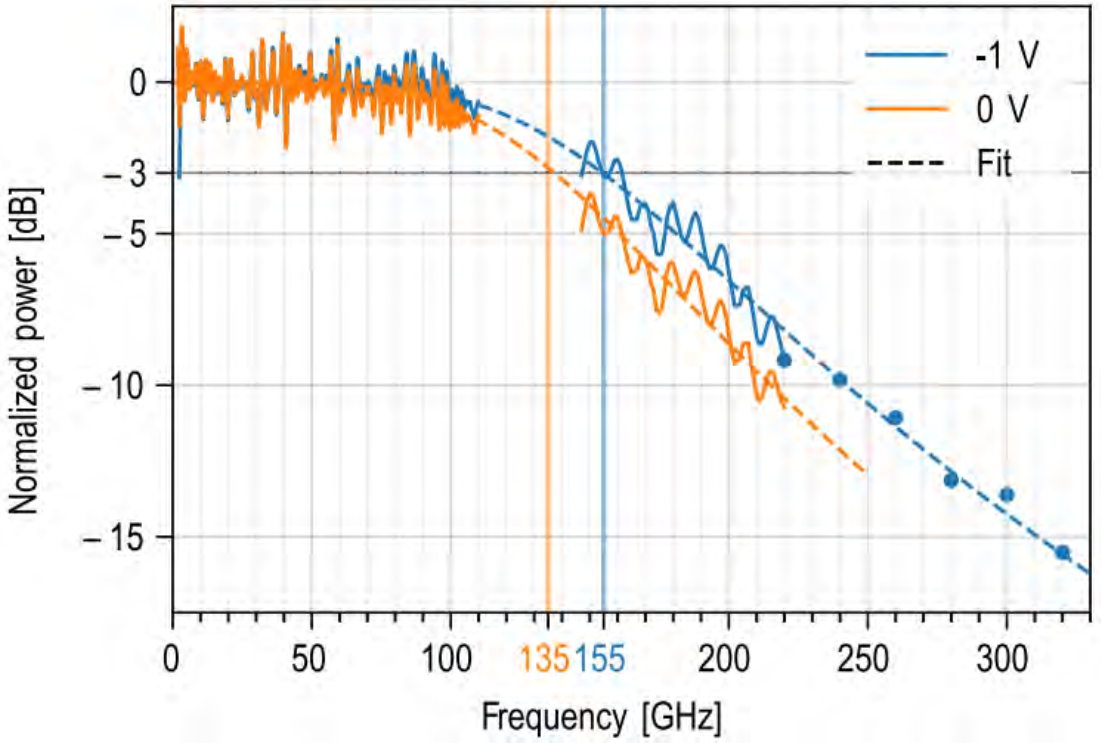


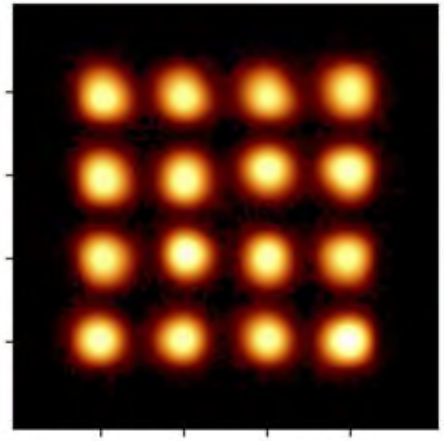
T. Vandekerckhove, Optics materials express, CLEO 2023

Results highlighting

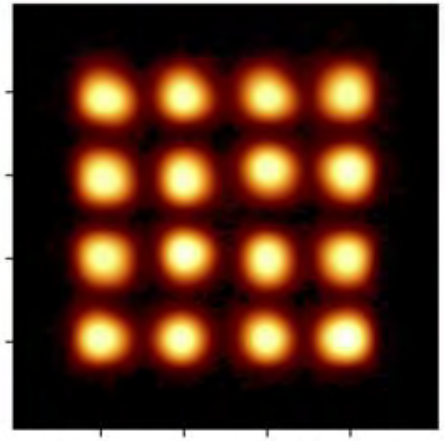
- **SiN/InGaAs for fast photomixing**



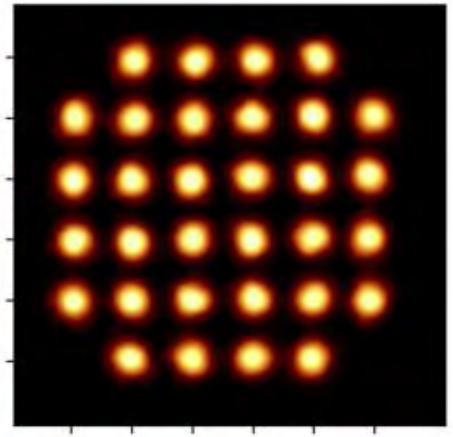




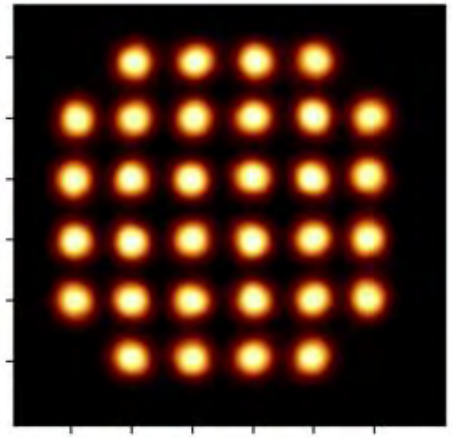
(a) 35 GBd (–1 V) 11.2% EVM



(b) 35 GBd (0 V) 11.9% EVM



(c) 25 GBd (–1 V) 7.0% EVM



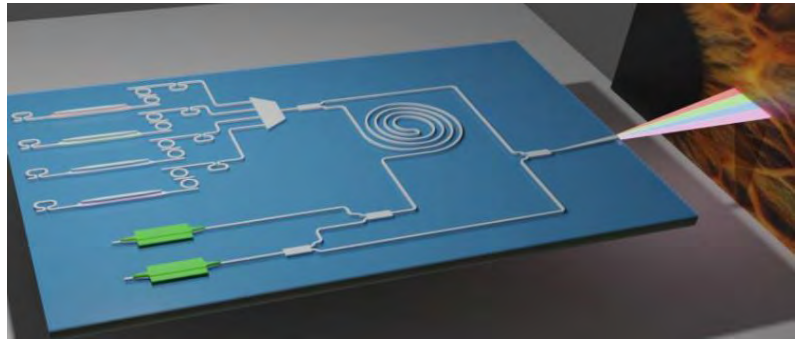
(d) 25 GBd (0 V) 7.5% EVM

D. Maes et al, APL photonics

Toward system level heterogeneous integrated photonics

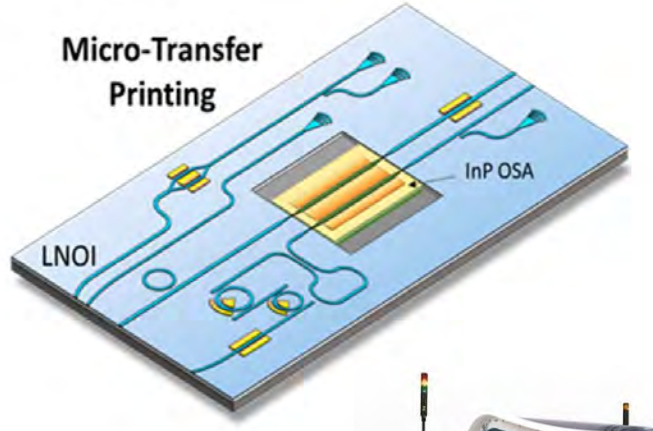
- **Horizon Europe VISSION** (Contact M. Billet / UGent-Imec / technical coordinator)

Devices	Technology
Routing / circuit	SiN
Laser visible/NIR	Transfer printing
Fast modulators	Transfer printing / inject printing
Fast detectors	Transfer printing



- **Horizon Europe PATTERN** (Contact A, Ghadimi / CSEM / technical coordinator)

Devices	Technology
Routing / circuit	LN
Laser 1550 nm	Transfer printing / flip chip
Fast modulators	LN circuit
Detectors	Flip-chip
RF building blocks	Transfer printing / flip-chip



- **Wafer scale (300 mm) pilot-line at UGent, end of 2023** (Contact Pr. G. Roelkens / UGent -Imec)

  - Transfer-printer (Amicra Nano MTP)
  - UV-litho
  - Metal deposition
  - Inspection tools…

+ working in parallel with R&D industrial partners

Summary

- **Presentation of the silicon nitride platform**
  - The SiN platform is very promising for optical circuitry
  - SiN is a dielectric, making difficult direct active functionalities
- **Heterogeneous integration via micro-transfer printing**
  - Micro-transfer printing offers a versatile solution to integrate functionalities on SiN
- **Challenges related to the processing**
  - Micro-transfer printing requests dedicated process flows development
- **Results highlighting**
  - Several convincing results have been already demonstrated
  - Need to push the technology forward scalable system level

Thank you for your attention

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Appendix

230 nm

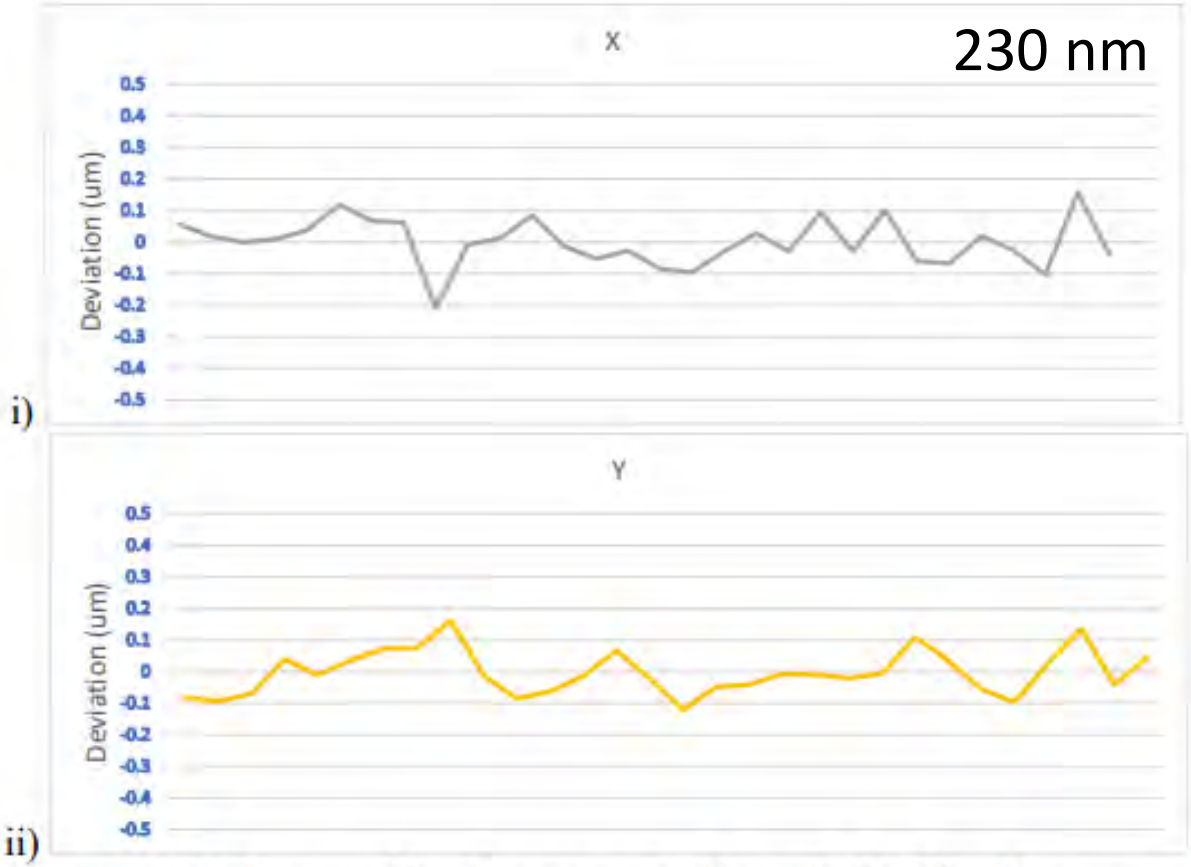

Fig. 7. 2x2 Array displacement data: i) X displacement; and ii) Y displacement.

Micro Transfer Printing for Micro Assembly of Heterogeneous Integrated Compound Semiconductor Components

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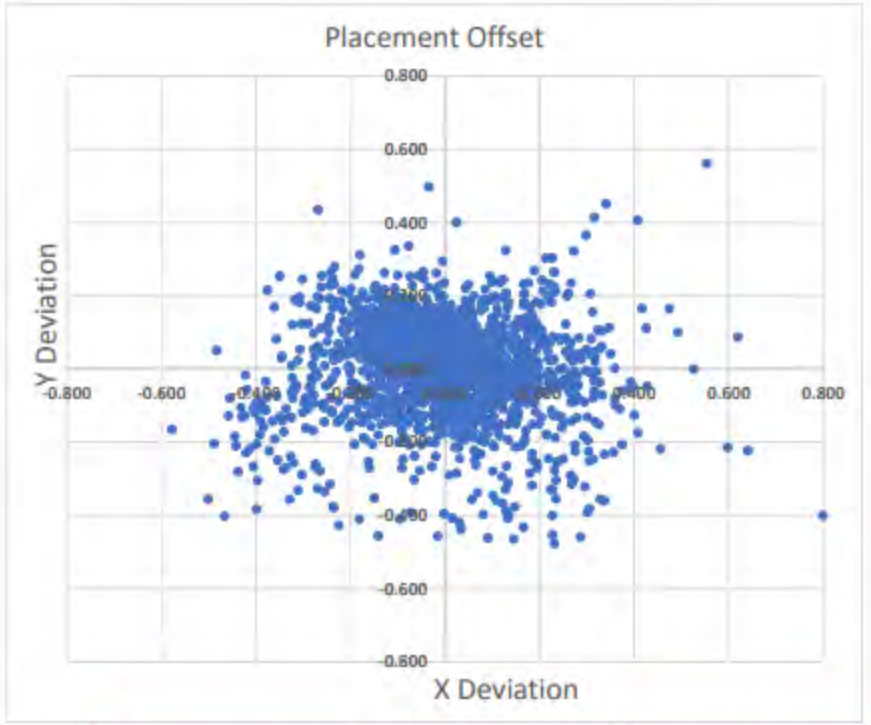
1. X-Celeprint Inc., 3021 Cornwallis Road, Research Triangle Park, NC 27709, USA
2. X-Celeprint Ltd., Tyndall National Institute,Lee Maltings Complex Dyke Parade, Cork, Cork, T12 R5CP, Ireland

500 nm



Accuracy	X	Y
3S StDev (µm)	0.49	0.40

Fig. 9 . 20x28 Array displacement map data for all four prints within 3 sigma for entire dataset.