Photonics Research Group / Ghent university / imec

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

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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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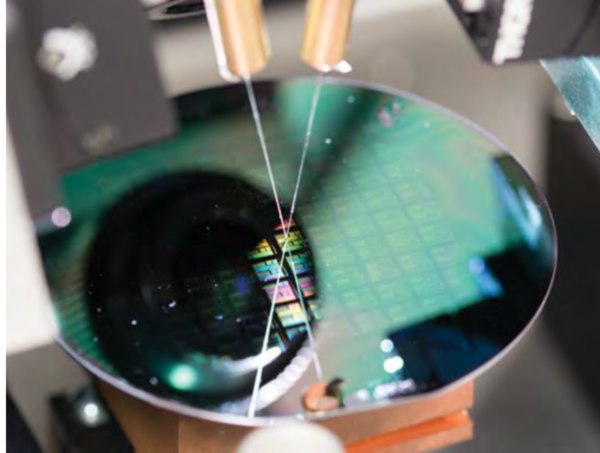
erc

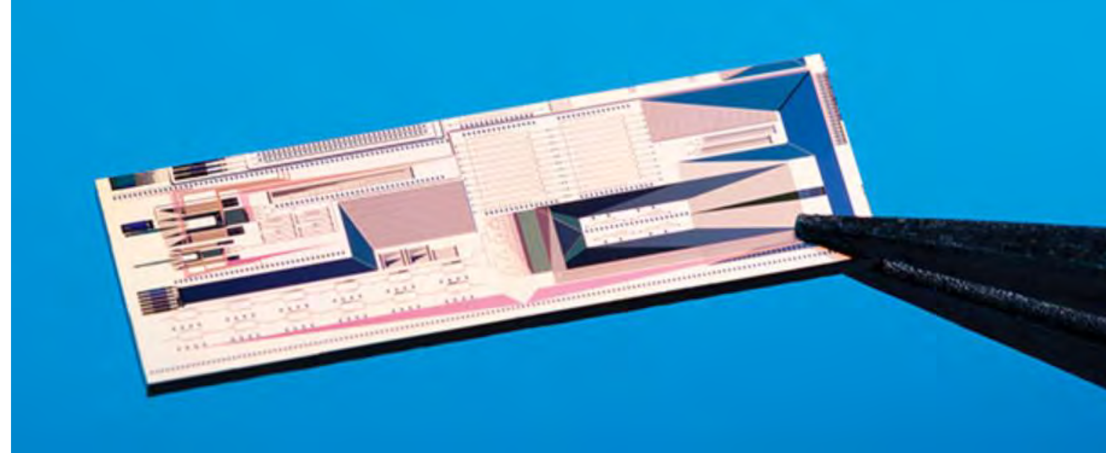
Contents

- **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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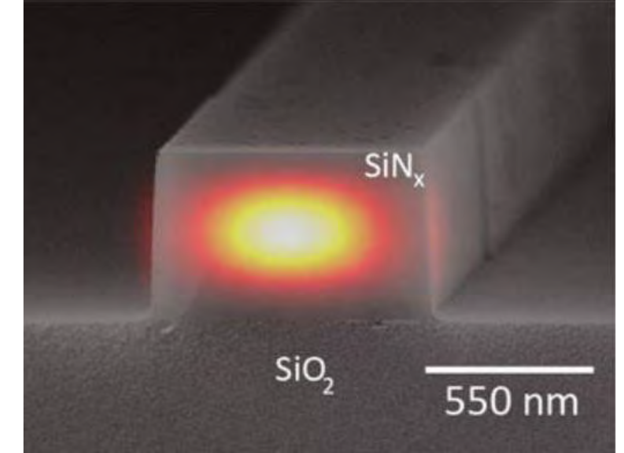


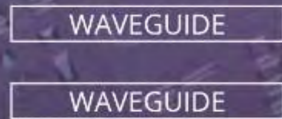
Source: CNST

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**

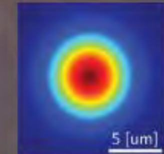
Ligentec website / passive components / process design kit available (MPW)



X2. Multi level photonics circuits

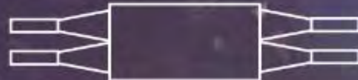
LoCA. Local cladding open for sensing and bonding

M1. High efficiency heater module for thermo-optic tuning

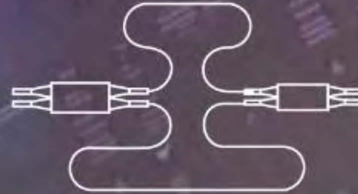


ExSpot. Spot size converters for mode matching to SMF in 1550nm

Low loss delay line



Splitter



Mach-Zehnder Interferometer

Phase shifter

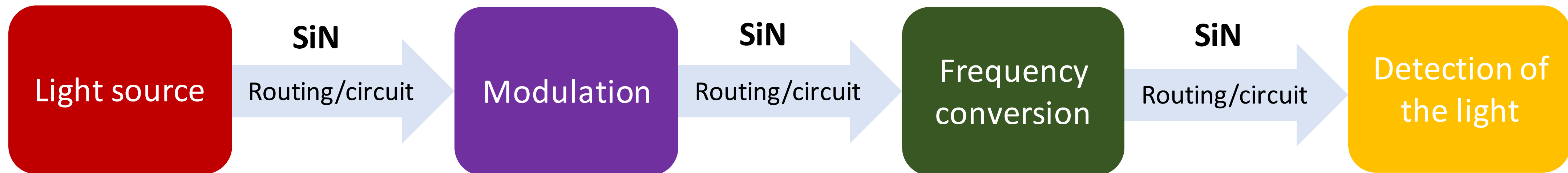
Tunable Mach-Zehnder

Tunable ring resonator

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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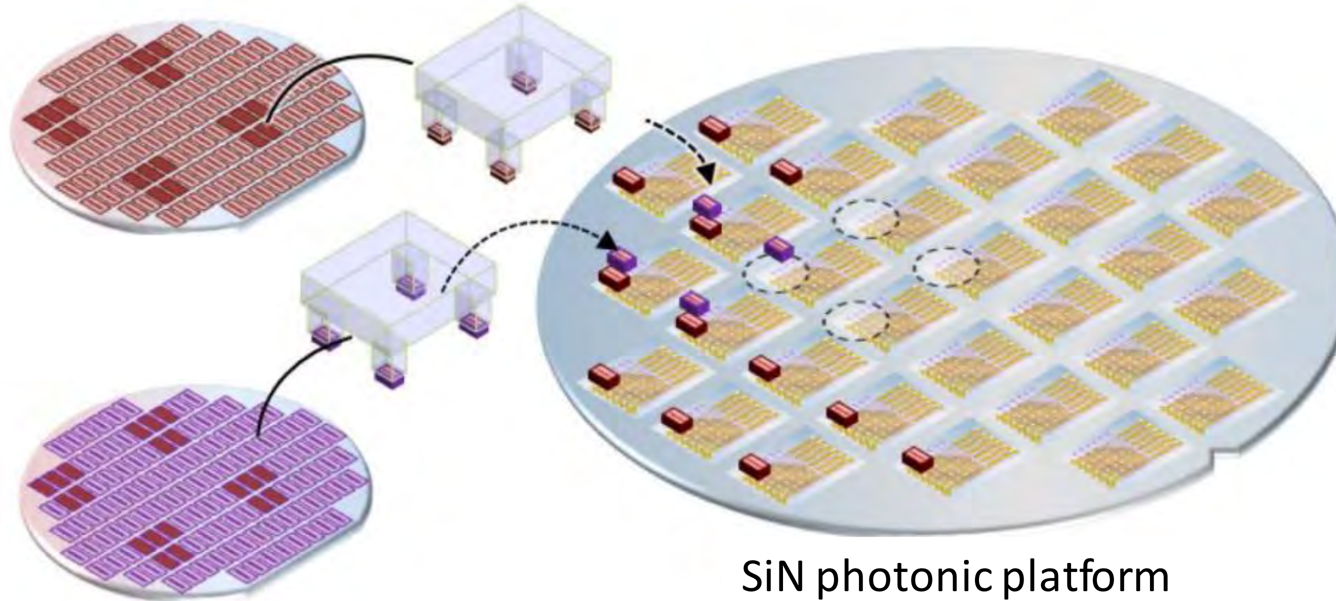
- Challenges related to the processing
- Results highlighting

Heterogeneous integration via micro-transfer printing

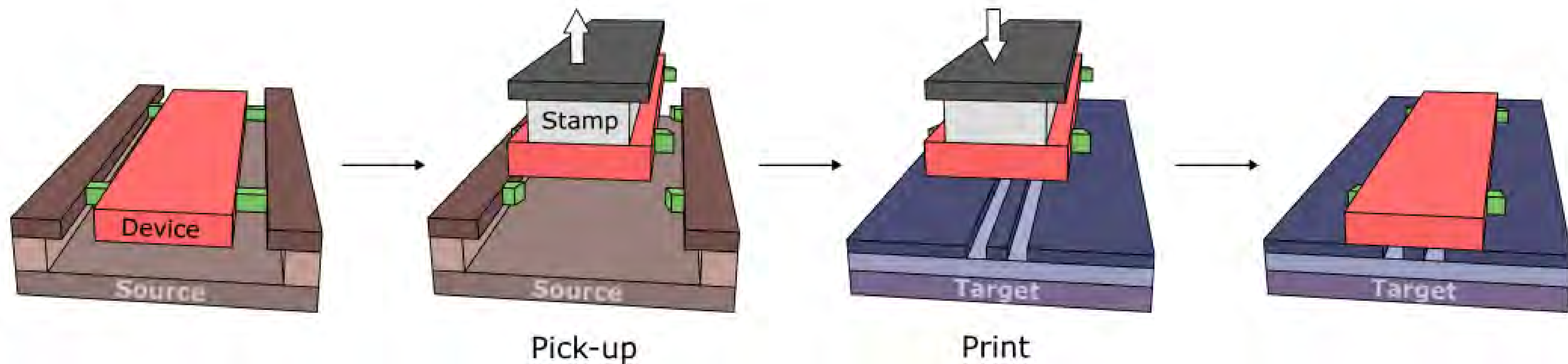
- **Using of micro-transfer printing as a versatile solution**



SiN photonic platform

Micro-transfer printing:

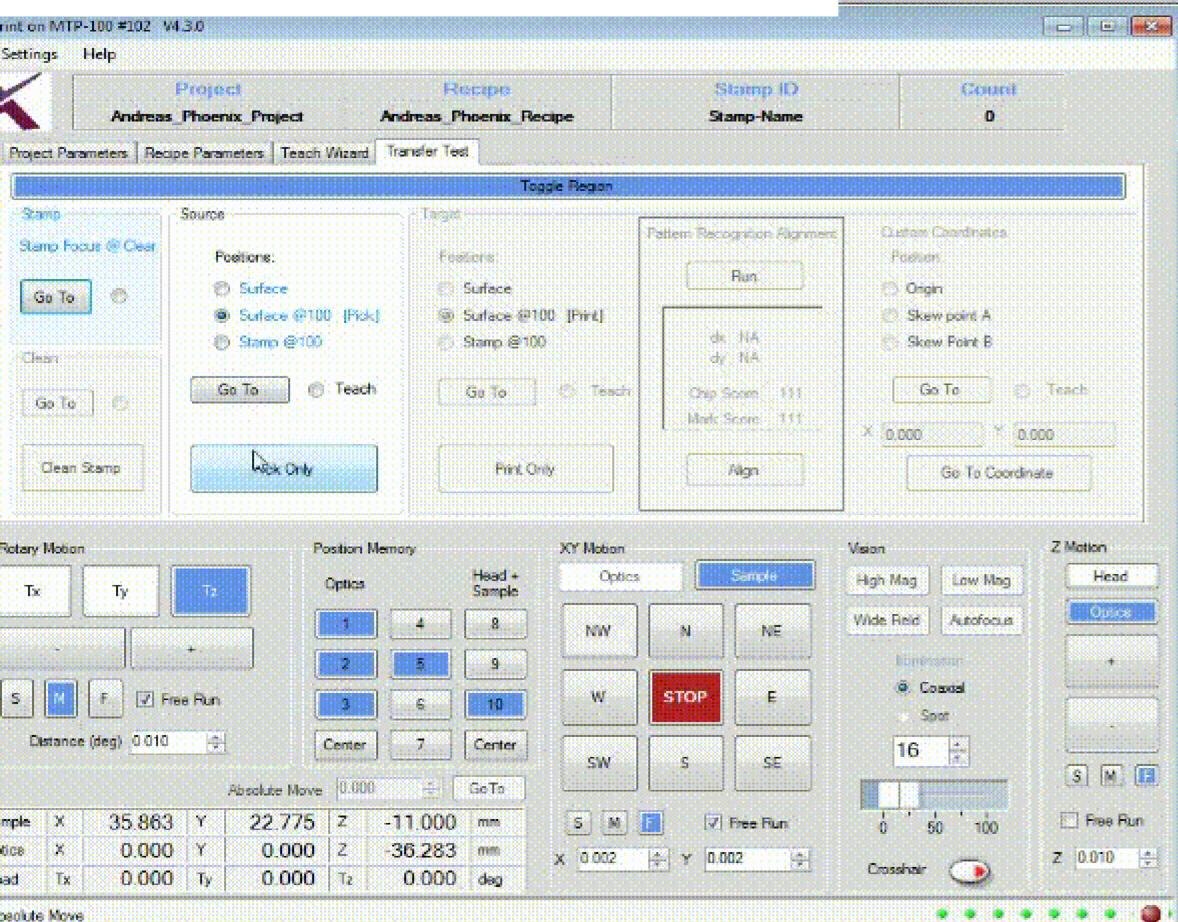
- High integration density
- Back-end compatible
- High efficiency of material use
- Alignment of 500 nm at 3σ
- High versatility for co-integration
- Low cost
- R&D maturity



Heterogeneous integration via micro-transfer printing

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

1 printing cycle ~ 1 min



Microscope
Robotized stage

Stamp

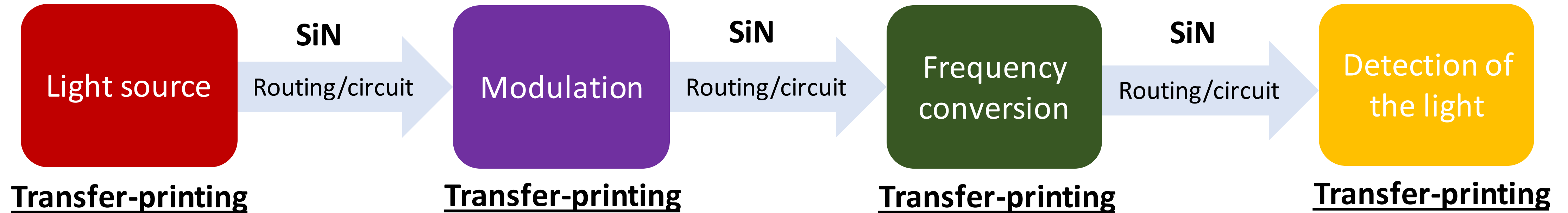
Coupon

Focusing on Source sample
Driving to the coupon

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
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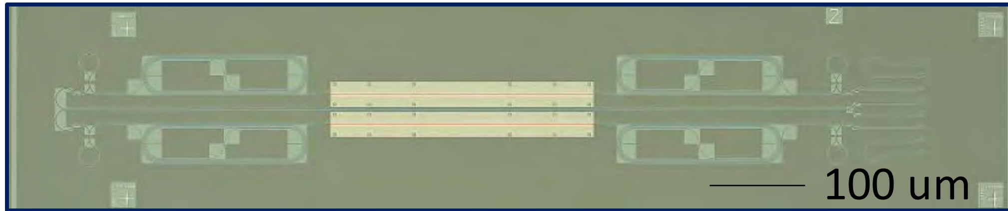
- **Challenges related to the processing**
- Results highlighting

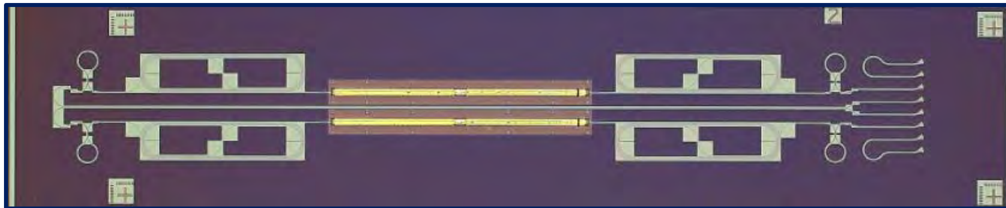
Challenges related to the processing

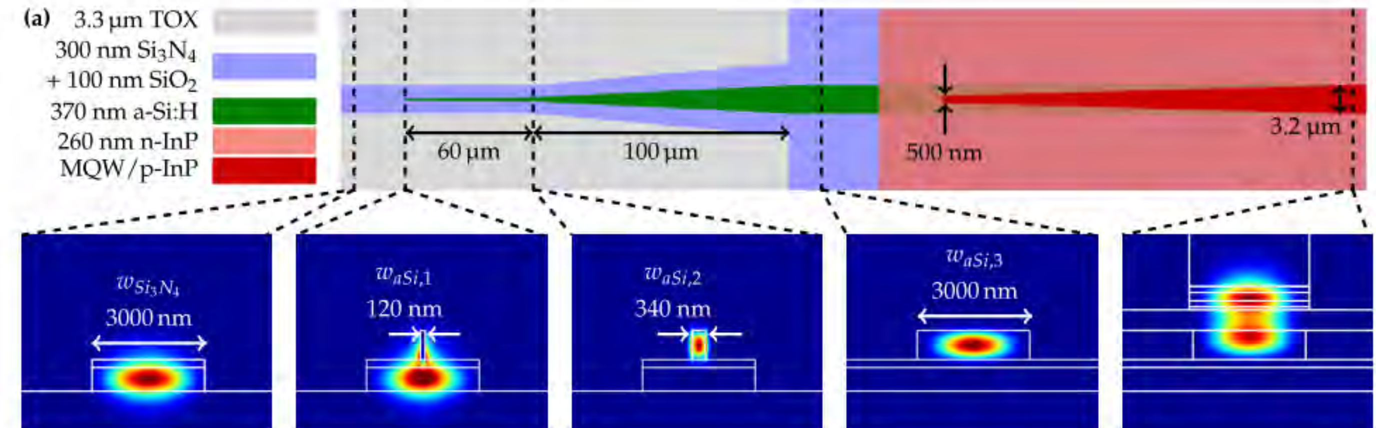
- **Coupling from SiN to devices using adiabatic tapers**

Passive SiN circuit



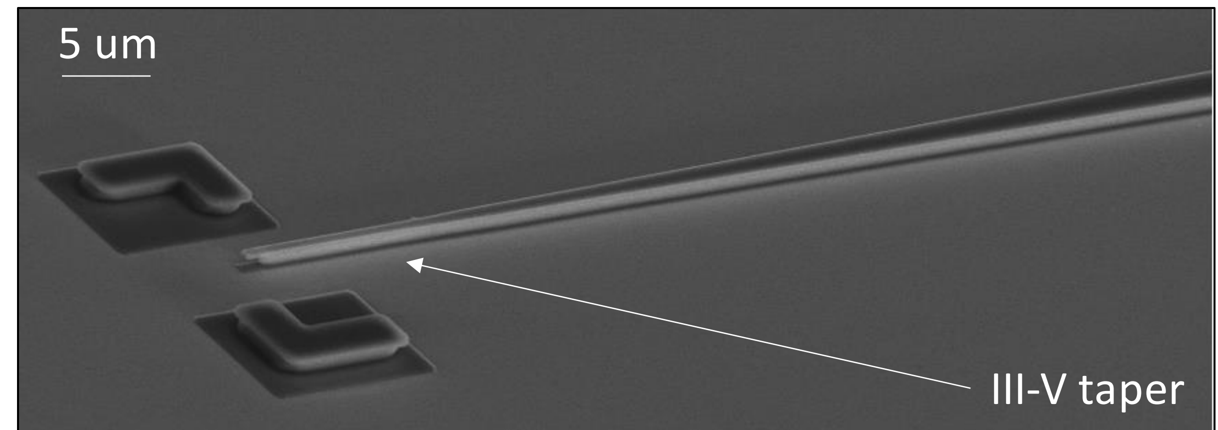
Printing of III-V amplifiers





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

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



Challenges:

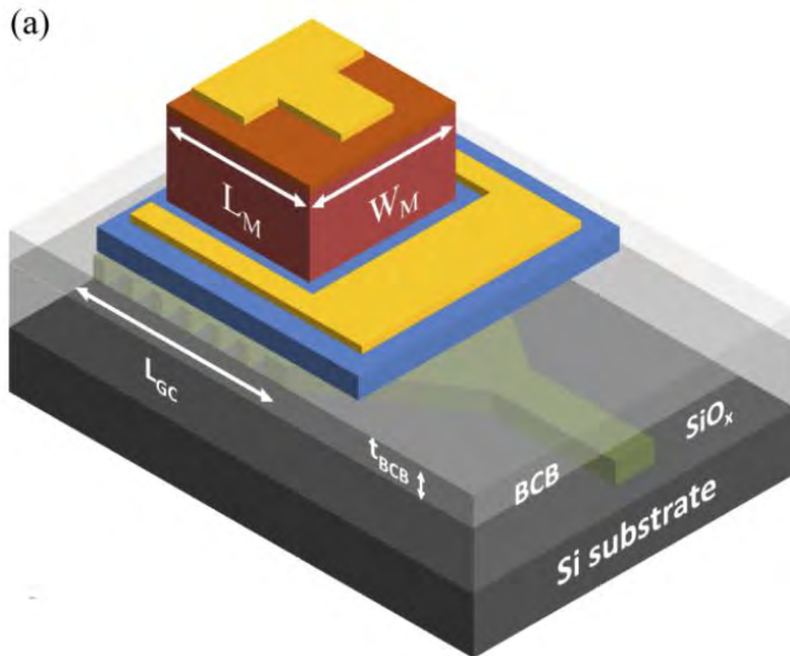
- **High aspect ratio etching / optical sidewall quality**
- **Intermediate aSi layer (custom platform) / aSi recipes depends on the Fab (index, stress…)**

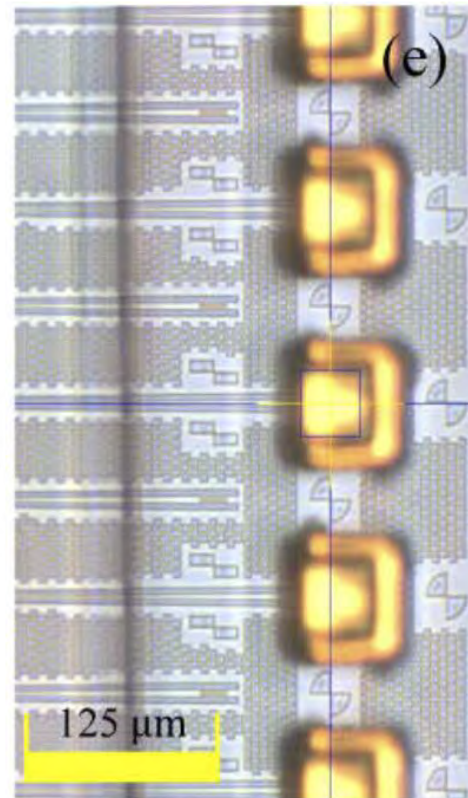
Challenges related to the processing

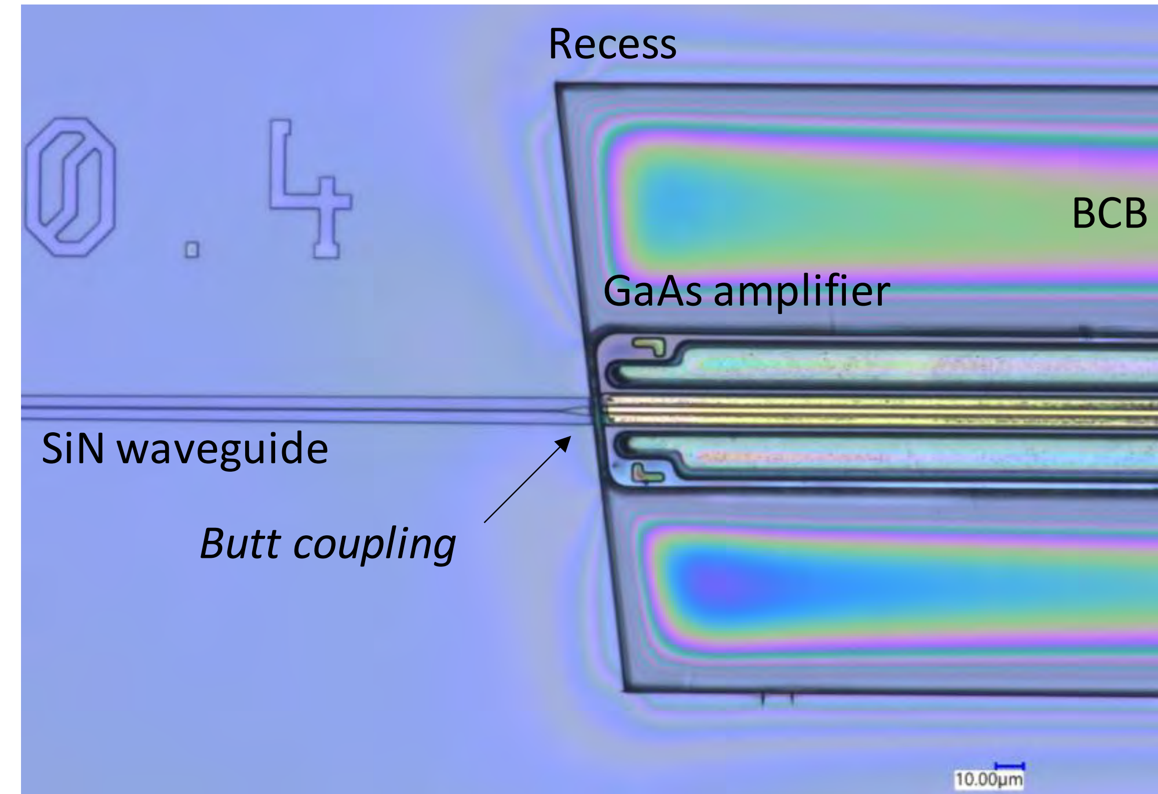
- **Coupling from SiN to devices using grating coupler / butt coupling**

Grating coupler assisted coupling

Direct butt coupling from the facet of the waveguide







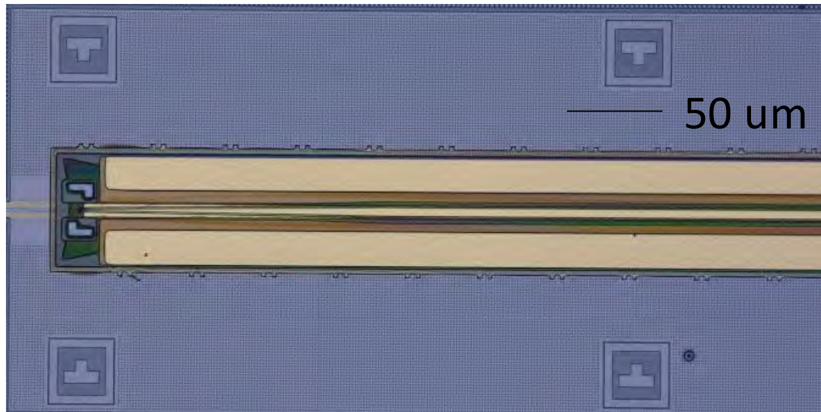
Challenges:

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

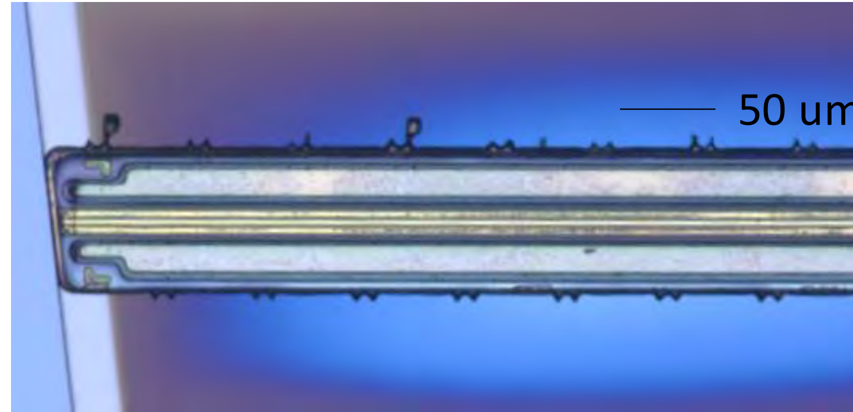
Challenges related to the processing

- **Wavelength compatibility**

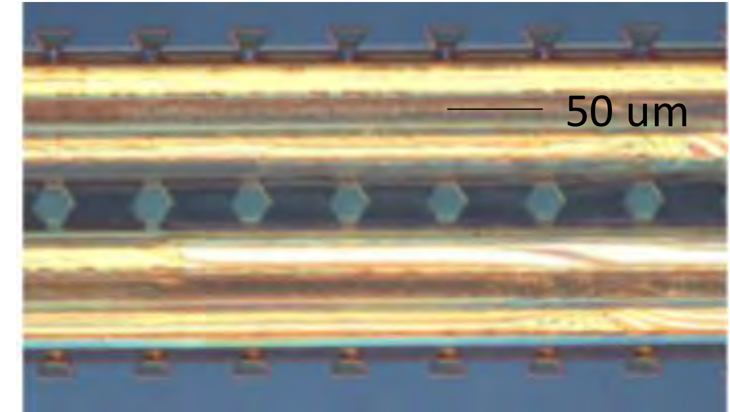
InP based amplifiers (IR~1550 nm)



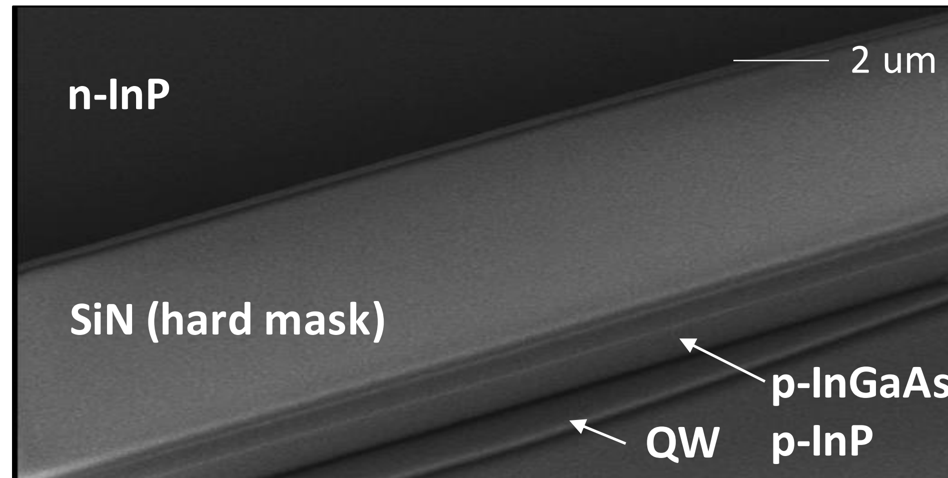
GaAs based amplifiers (NIR~800 nm)

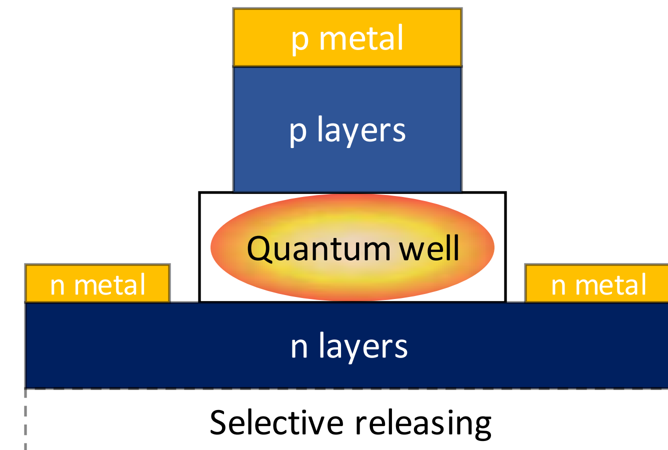


GaN based amplifiers (VIS~450 nm)



Typical coupon size 2 mm x 50 um





Challenges:

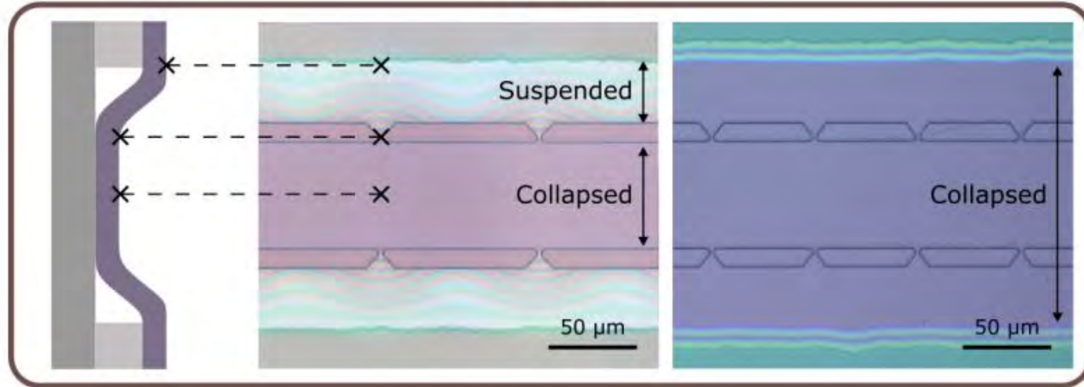
- **Full process flow for different III-V systems (Epitaxy / RIE / ICP / wet etching / releasing…)**

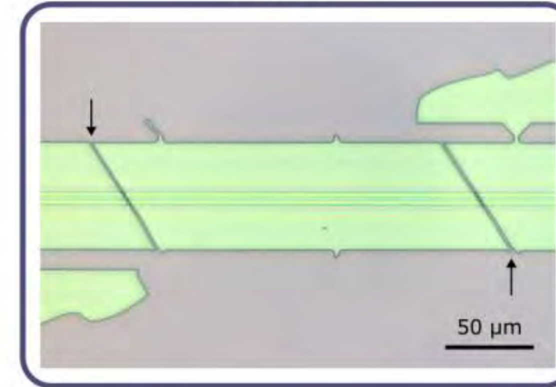
Challenges related to the processing

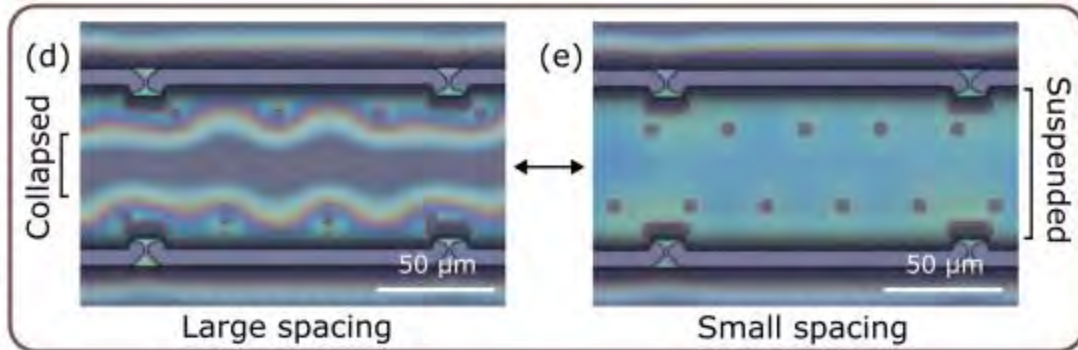
- Releasing / picking / printing of the devices

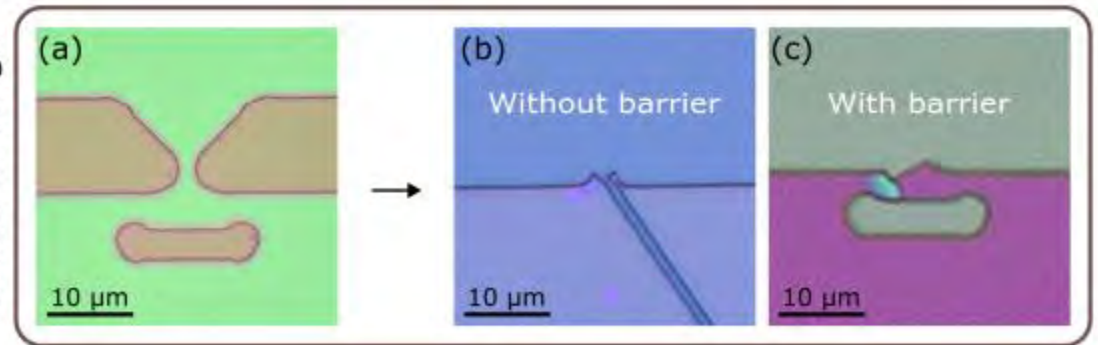
Source

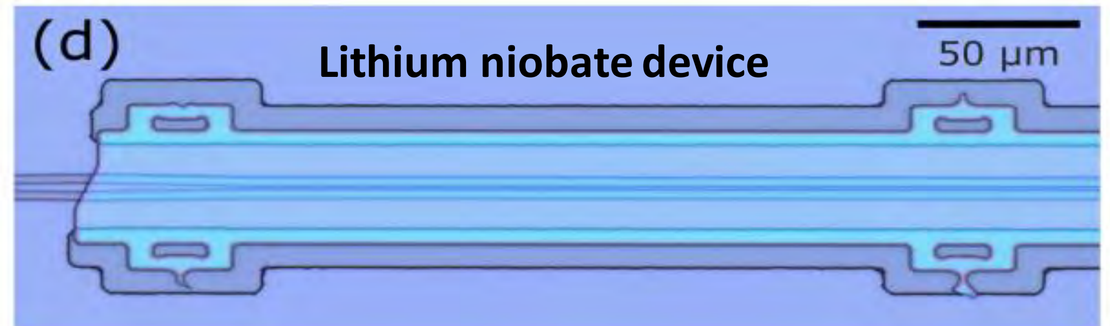
Target











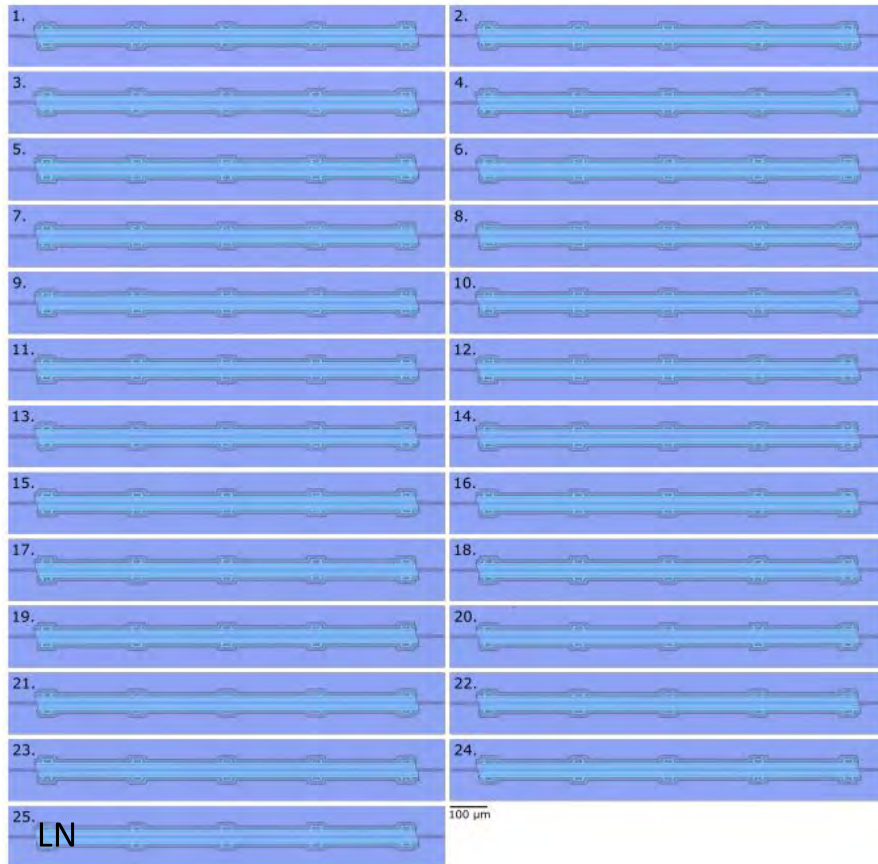
Challenges:

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

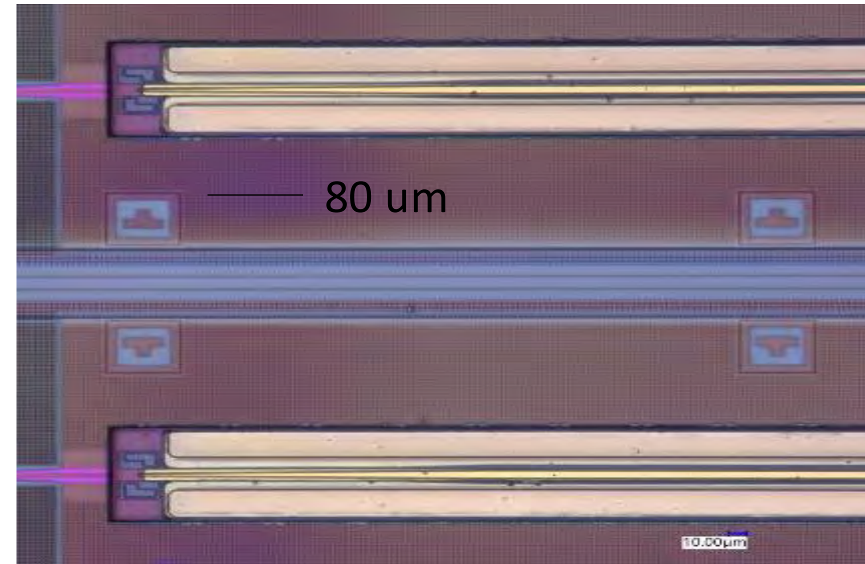
Challenges related to the processing

- **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)**

Contents

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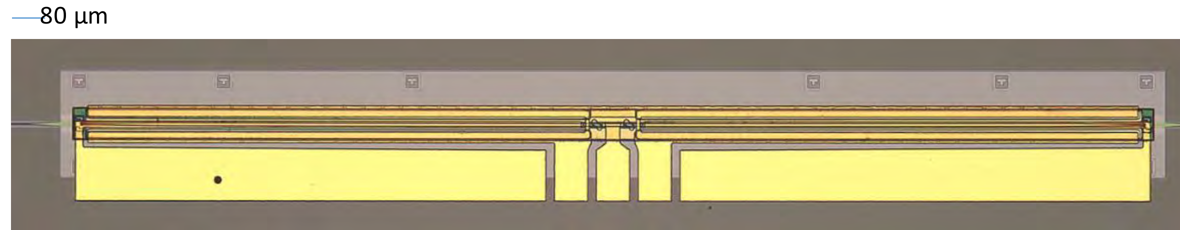
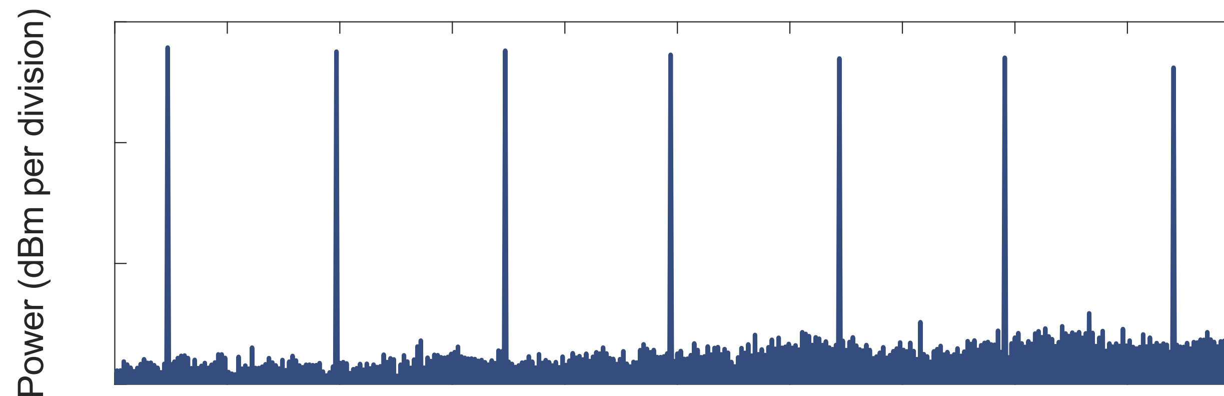
- **Results highlighting**

Results highlighting

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

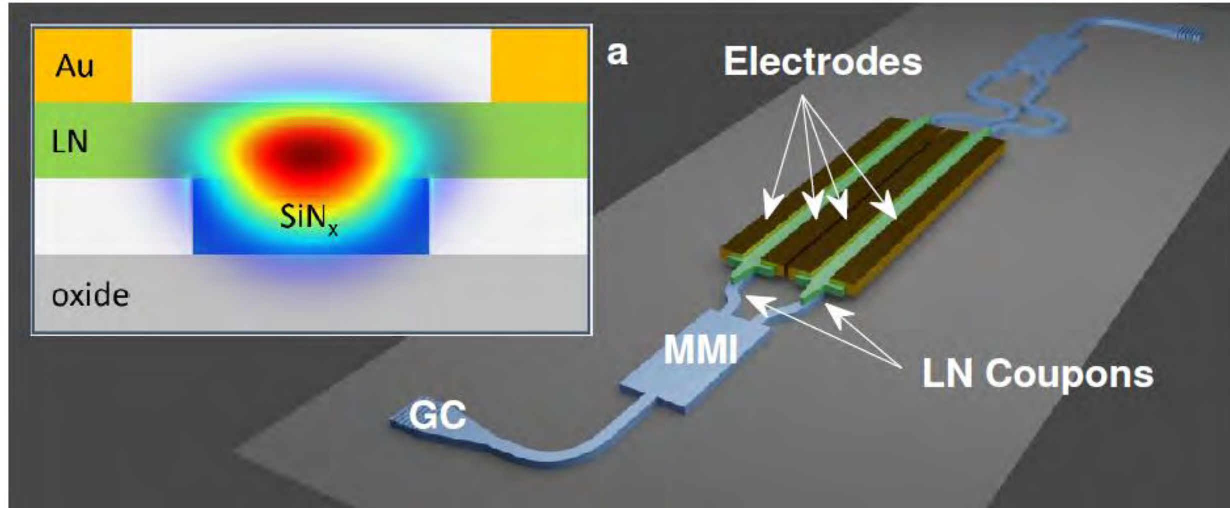


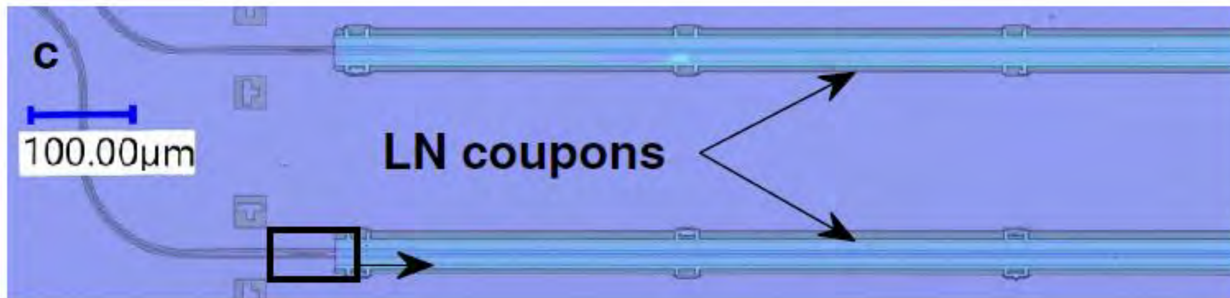
Repetition rate = 3 GHz

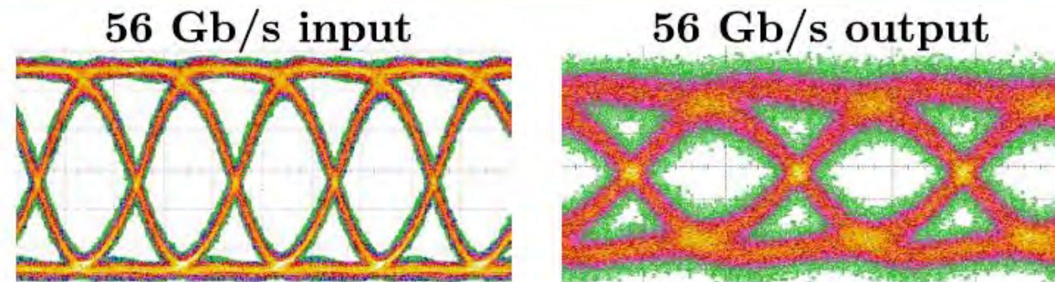


Results highlighting

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



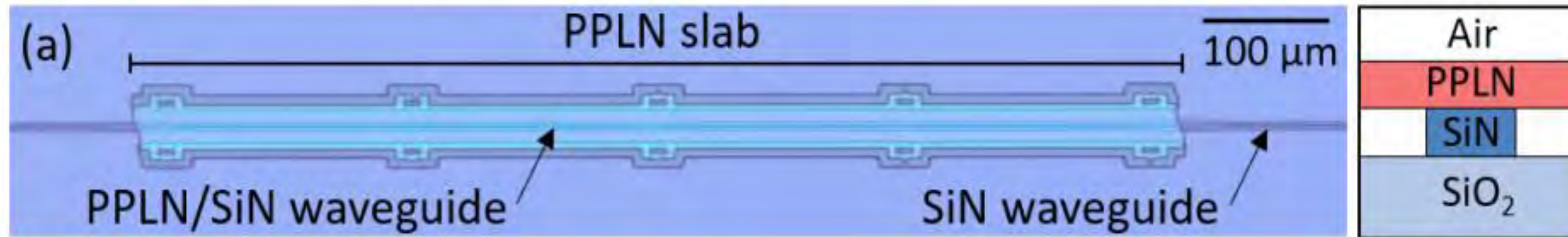


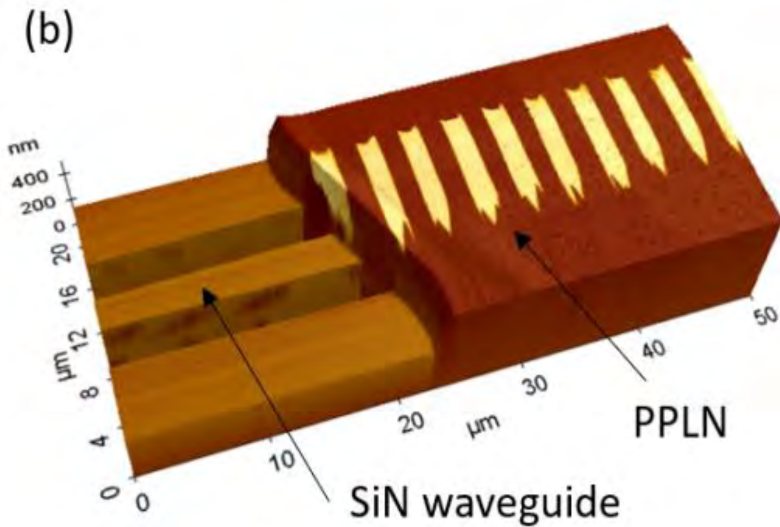


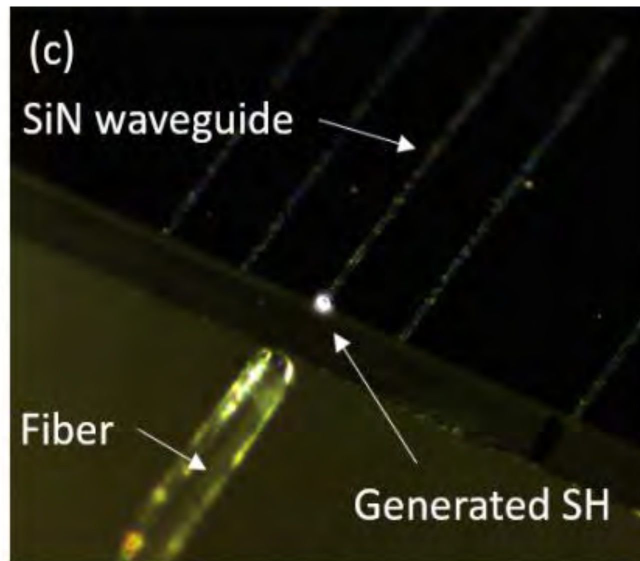
T. Vanackere et al, APL photonics/CLEO 2023

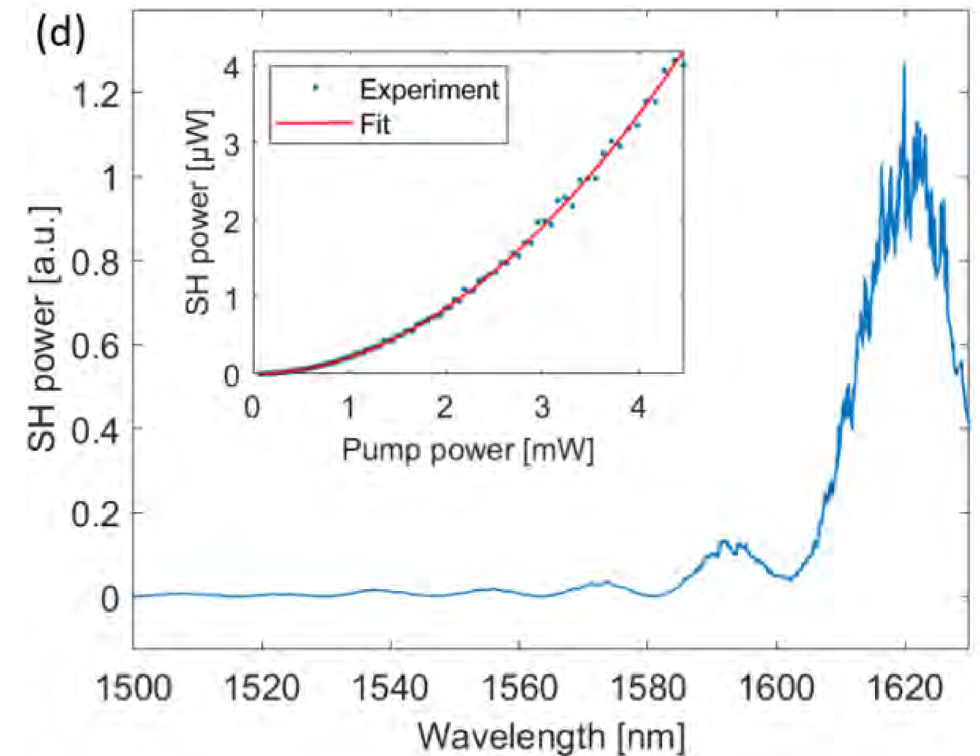
Results highlighting

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





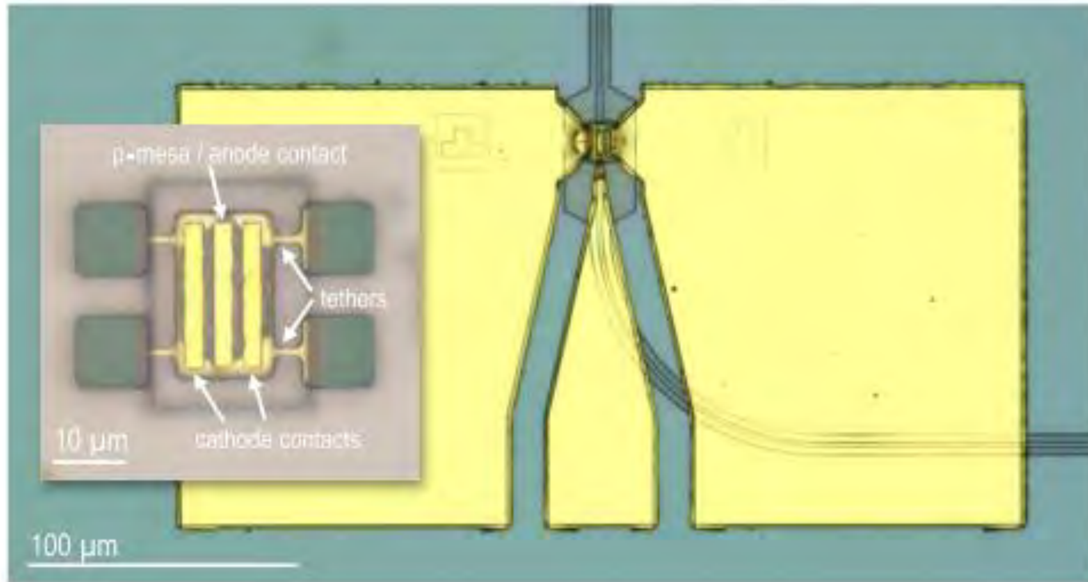


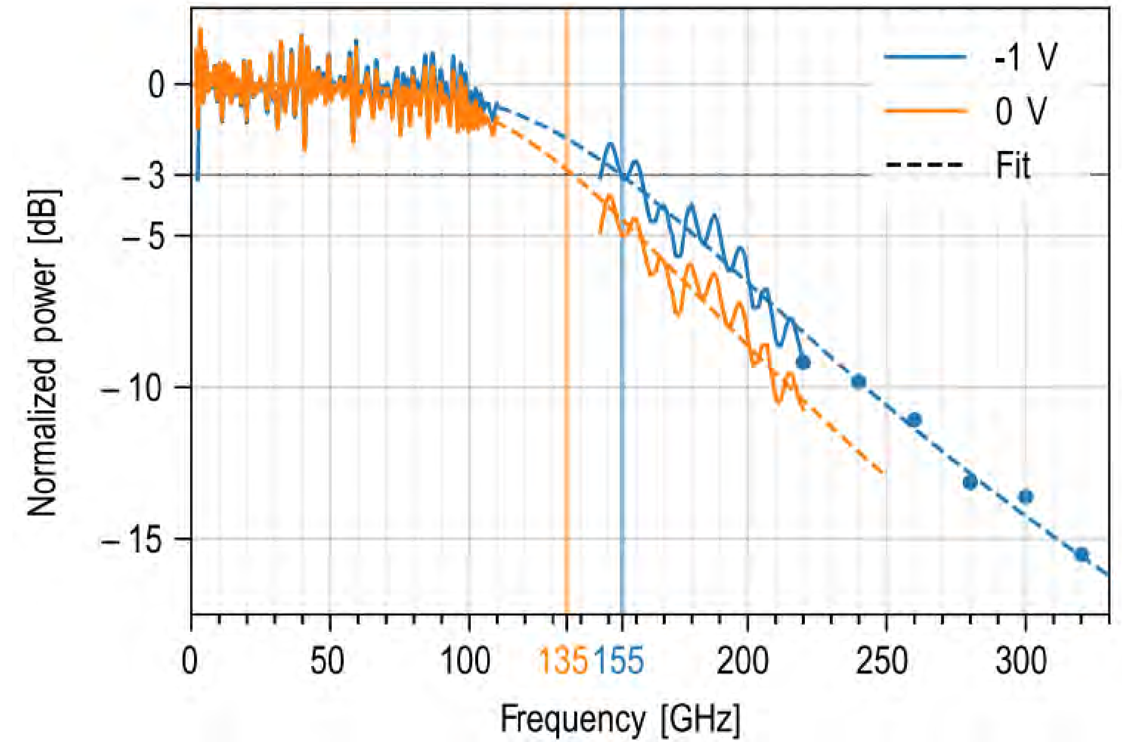


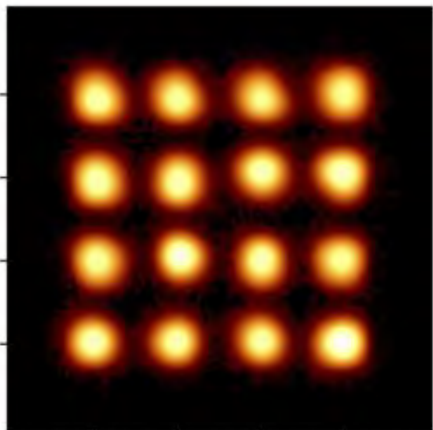
T. Vandekerckhove, Optics materials express, CLEO 2023

Results highlighting

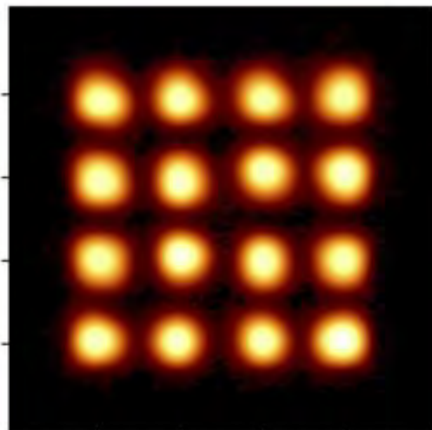
- **SiN/InGaAs for fast photomixing**



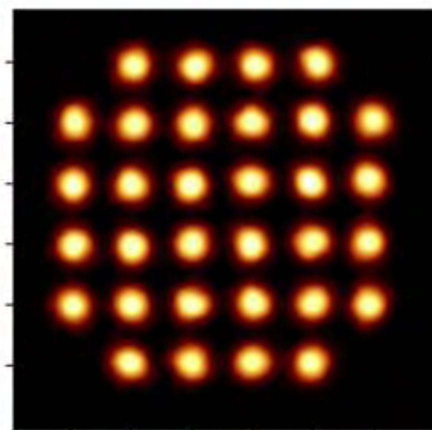




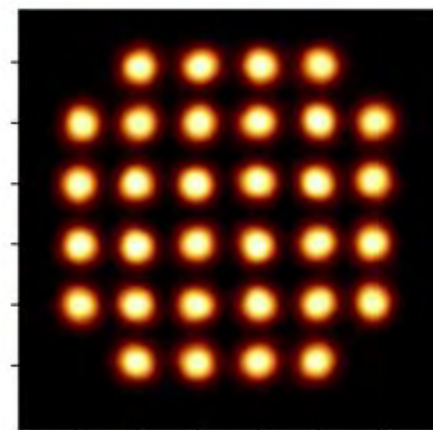
(a) 35 GBd (−1 V) 11.2% EVM



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



(c) 25 GBd (−1 V) 7.0% EVM



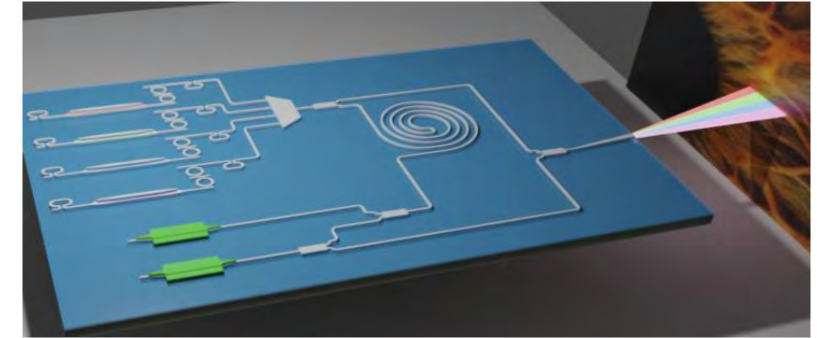
(d) 25 GBd (0 V) 7.5% EVM

D. Maes et al, APL photonics

Toward system level heterogeneous integrated photonics

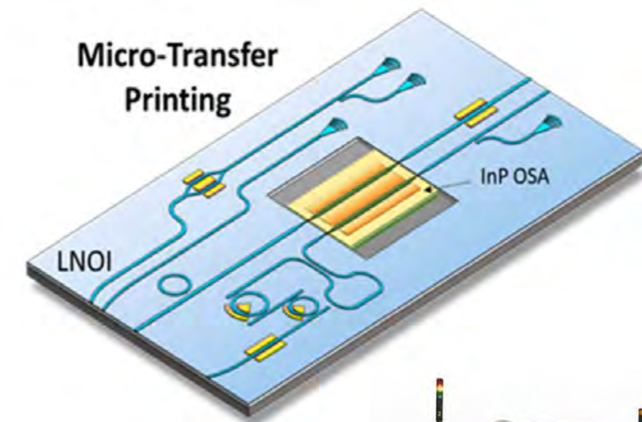
- **Horizon Europe VISSION** (Contact M. Billet / UGent-Imec / technical coordinator)

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

Appendix

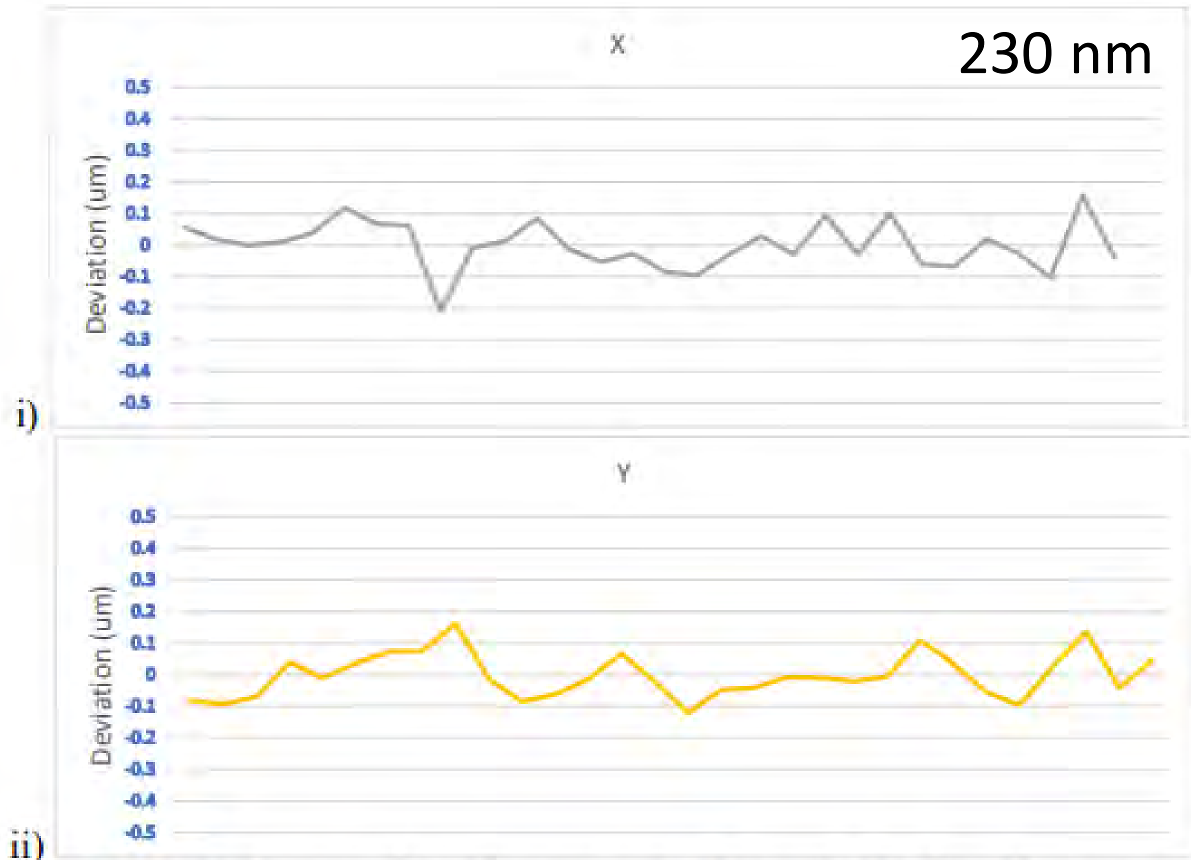
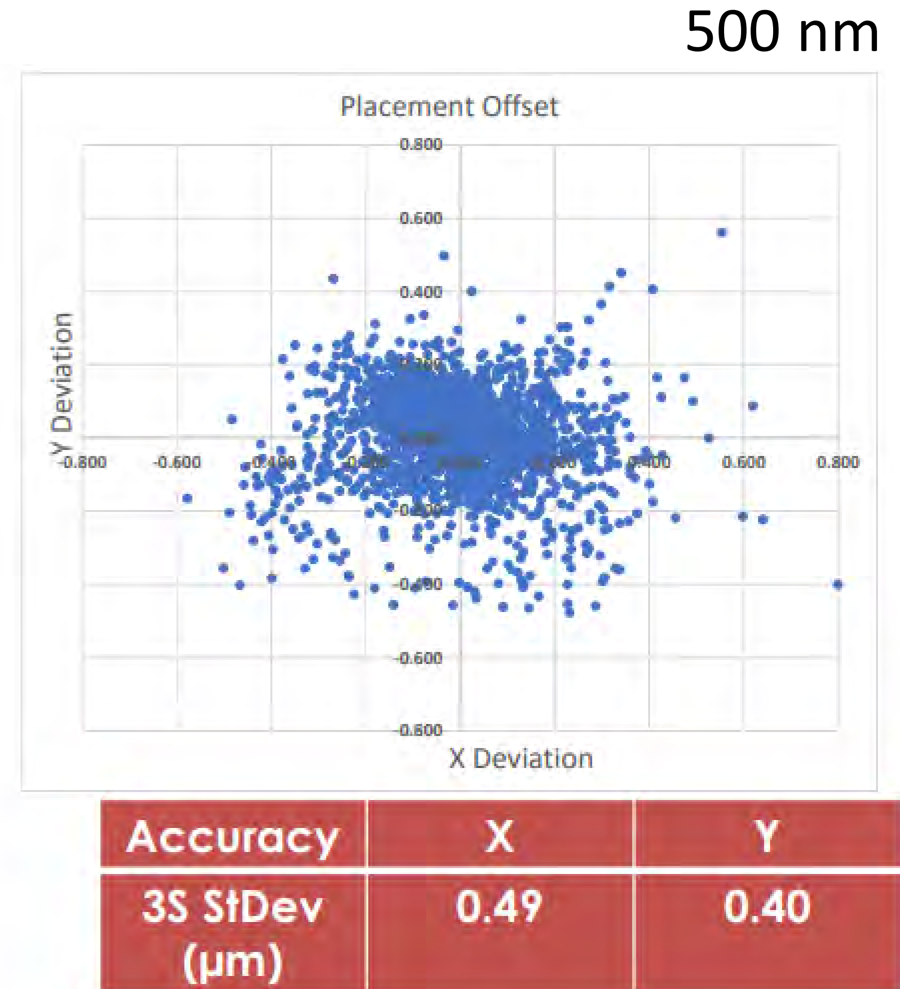


Fig. 7. 2x2 Array displacement data: i) X displacement; and ii) Y displacement.



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.

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

David Gomez[1], James Thostenson[1], Tanya Moore[1], Kevin Oswalt[1], Chris Reyes[1], Ron Cok[1], Alin Fecioru[2]

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2. X-Celeprint Ltd., Tyndall National Institute,Lee Maltings Complex Dyke Parade, Cork, Cork, T12 R5CP, Ireland