DEPARTMENT OF INFORMATION TECHNOLOGY (INTEC) – **PHOTONICS RESEARCH GROUP**

10 October
Update LEO 2024

High-Speed Electric-Optic Modulation with Lithium Niobate on a Silicon Photonics Platform

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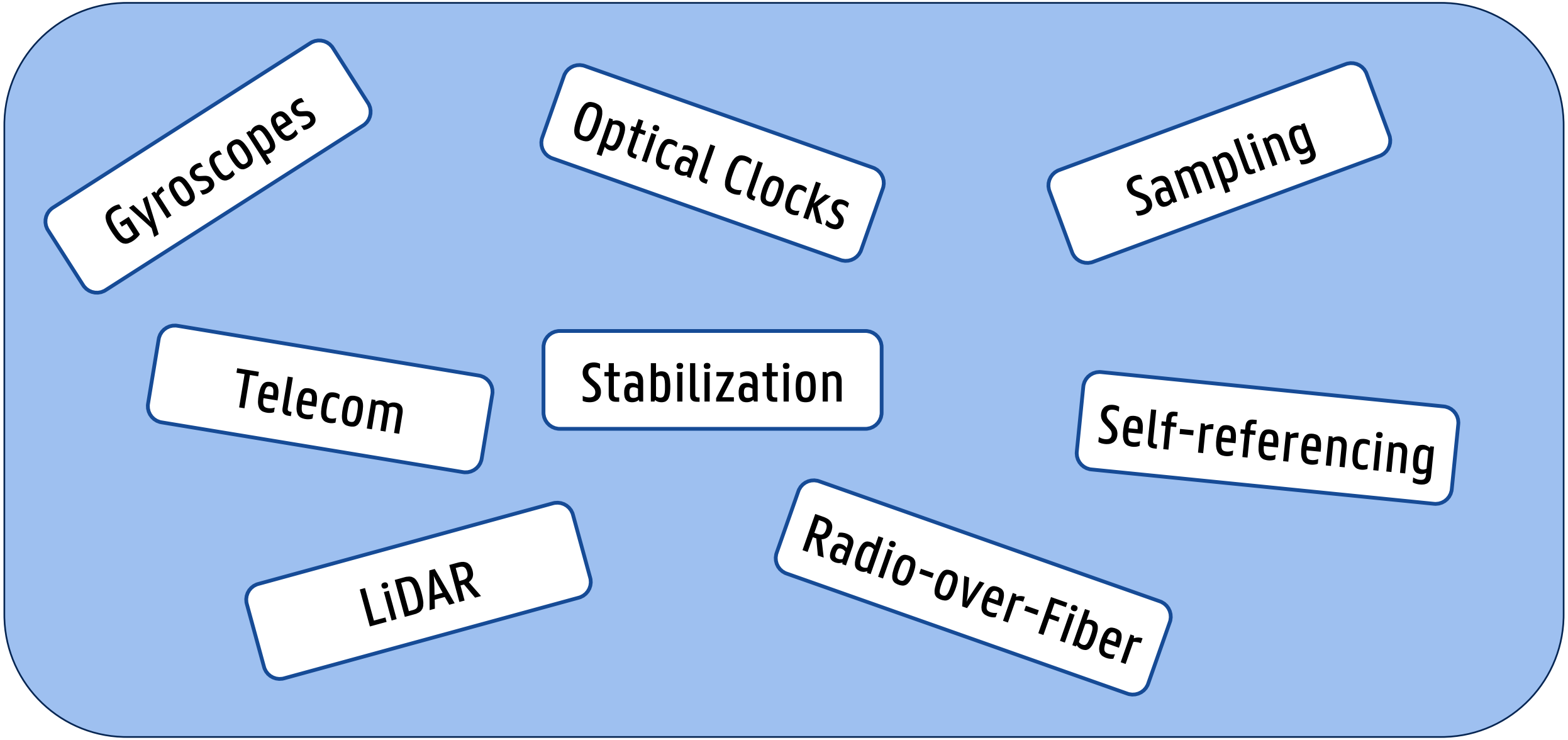
imec GHENT UNIVERSITY IDLab INTERNET & DATA LAB PRG esa

WP1 : Analysis of LiNbO3 for PNT systems



	Silicon-on-insulator	Silicon nitride	Indium Phospide	Expanded ISIPP200N
Refractive index	3.5	2.1	3.1	2.1-3.5
Waveguide refractive index contrast (%)	>100	>25	10	>25
Bending Radius (µm)	5-100	50-150	100	5-200
Loss (dB cm^{-1})	0.1-3	0.01-0.2	1.5-3	0.03-3
Nonlinear index ($m^2 W^{-1}$)	4.5×10^{-18}	2.6×10^{-19}	1.5×10^{-17}	4.5×10^{-18}
Two-photon absorption (cm GW^{-1})	0.25	Negligible	60	Negligible
Modulator Technology (maximum speed)	Free-carrier plasma dispersion (70 GHz)	With graphene (30 GHz) With PZT (40 GHz)	QCSE-EAM (55 GHz)	Free-carrier plasma dispersion (70 GHz) LN (100 GHz)
Detector	Ge (50 GHz)	N/A	110 GHz	Ge (50 GHZ) InP (140 GHz)
Laser output power	N/A	N/A	>20 mW	>100 mW
Fibre-to-chip coupling loss (dB)	2	0.5	3	0.5
CMOS compatibility	Excellent	Good	N/A	Good
Optical amplification	N/A	N/A	>20 dB	>25 dB
SHG (Self referencing)	N/A	N/A	Yes	Yes

General advantages of LN modulators compared to other modulators

Fast Modulation

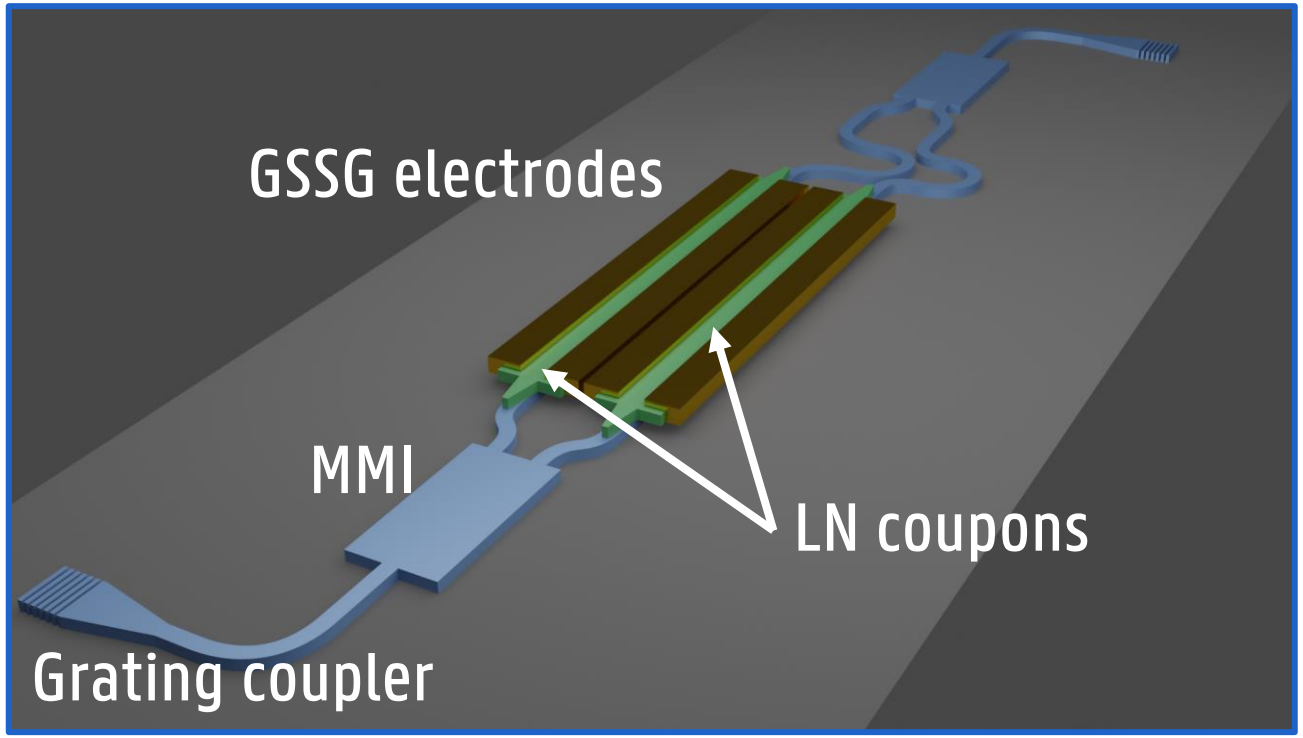
Low loss

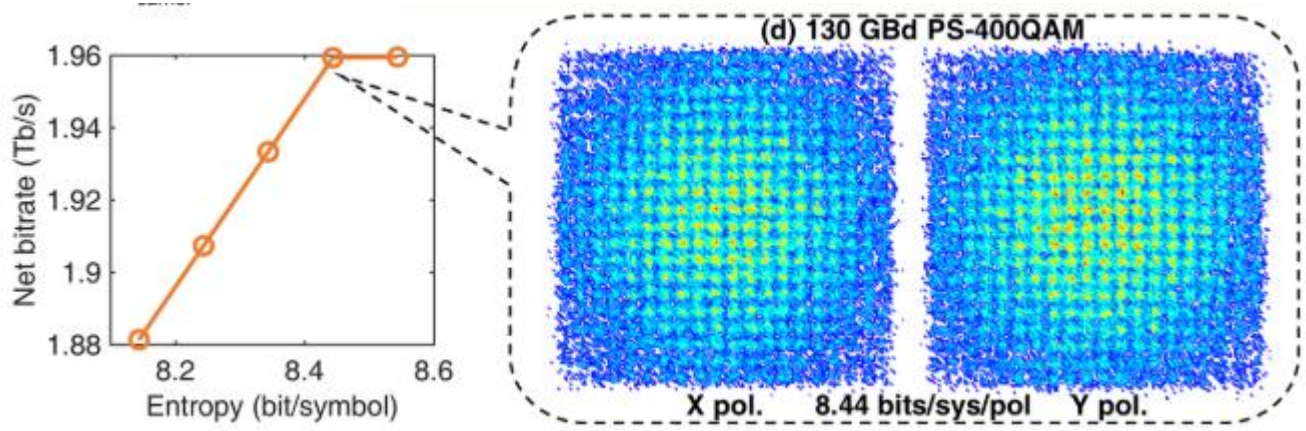
Perfectly linear modulation

Low RF power

High optical power handling

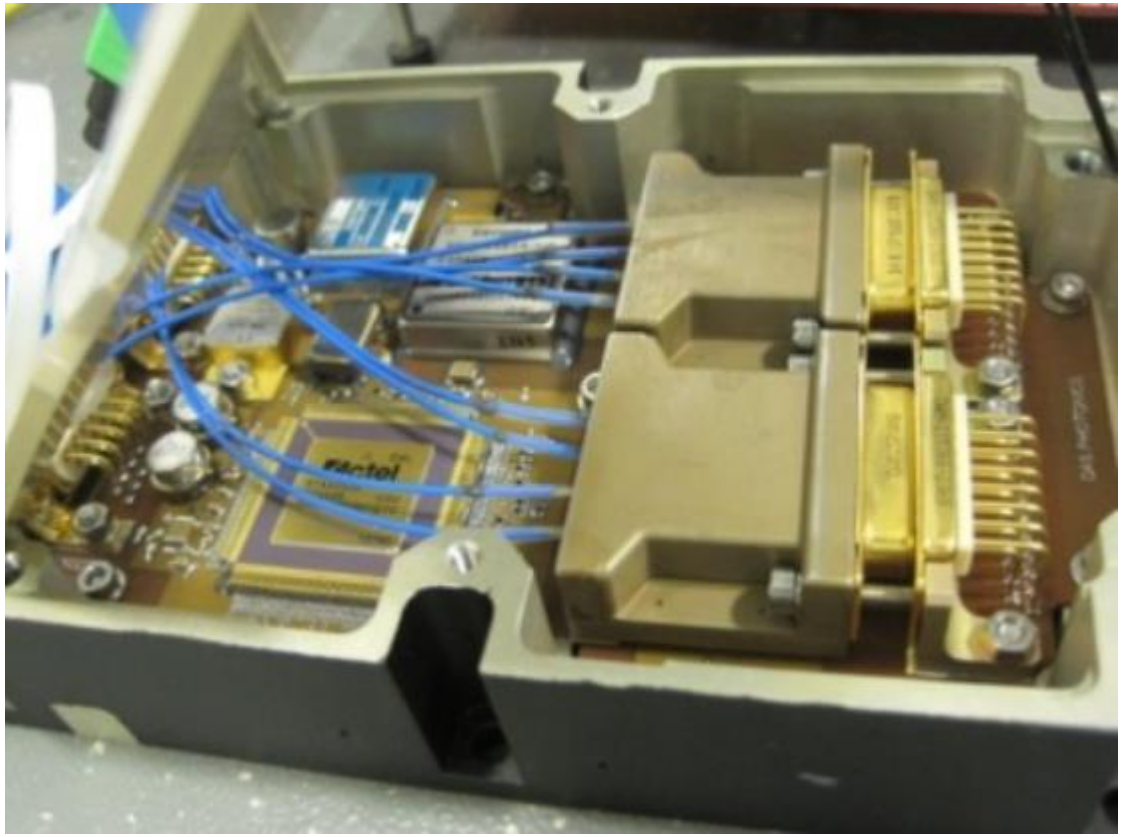
C-band, O-band, Visible wavelengths





M. Xu et. al, *Optica* (2022): doi.org/ 10.1364/optica.449691

Communications in space with low SWAP



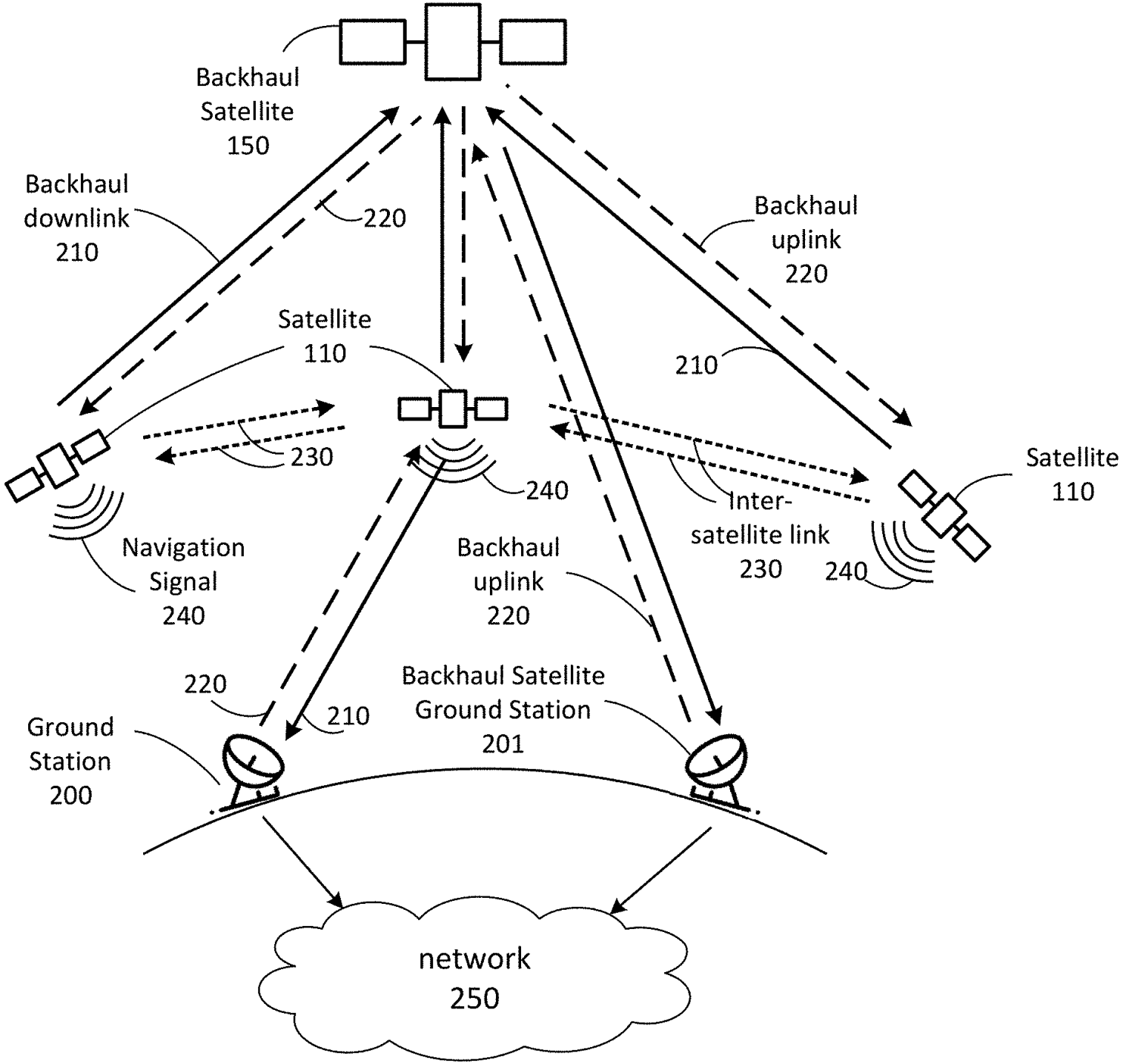
Very efficient linear modulation

Applications:

- RF-photonics
- Analog fiber links
- Radio-over-Fiber
- Photonic-assisted sampling
- LO distribution
- All types of communications

Patent for interconnected LEO and non-LEO satellites

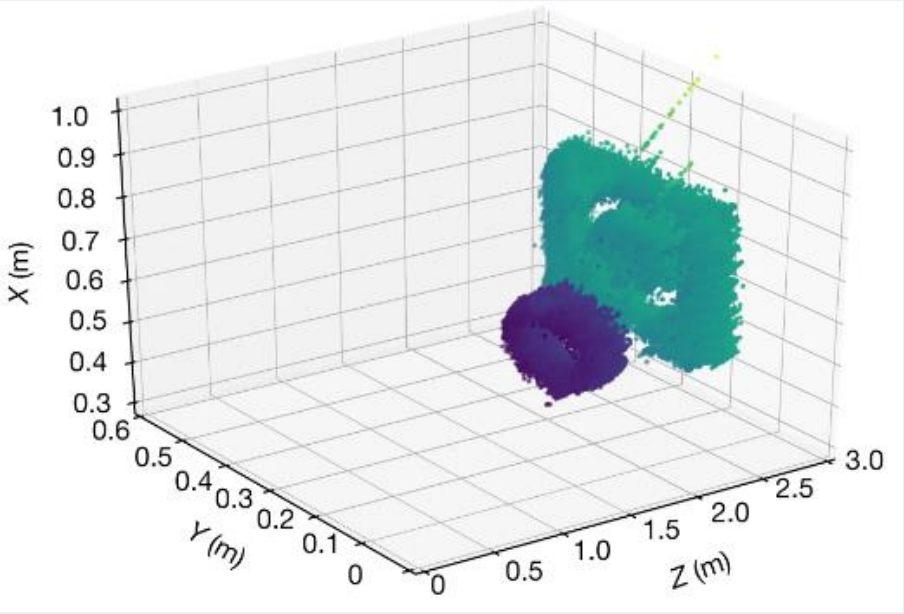
For more accurate orbital correction data and timing correction data in navigation satellites



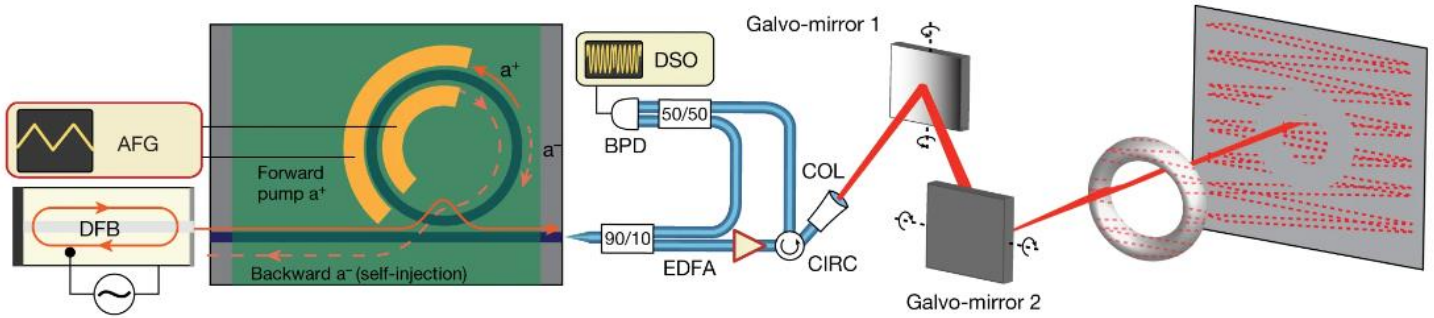
LiDAR

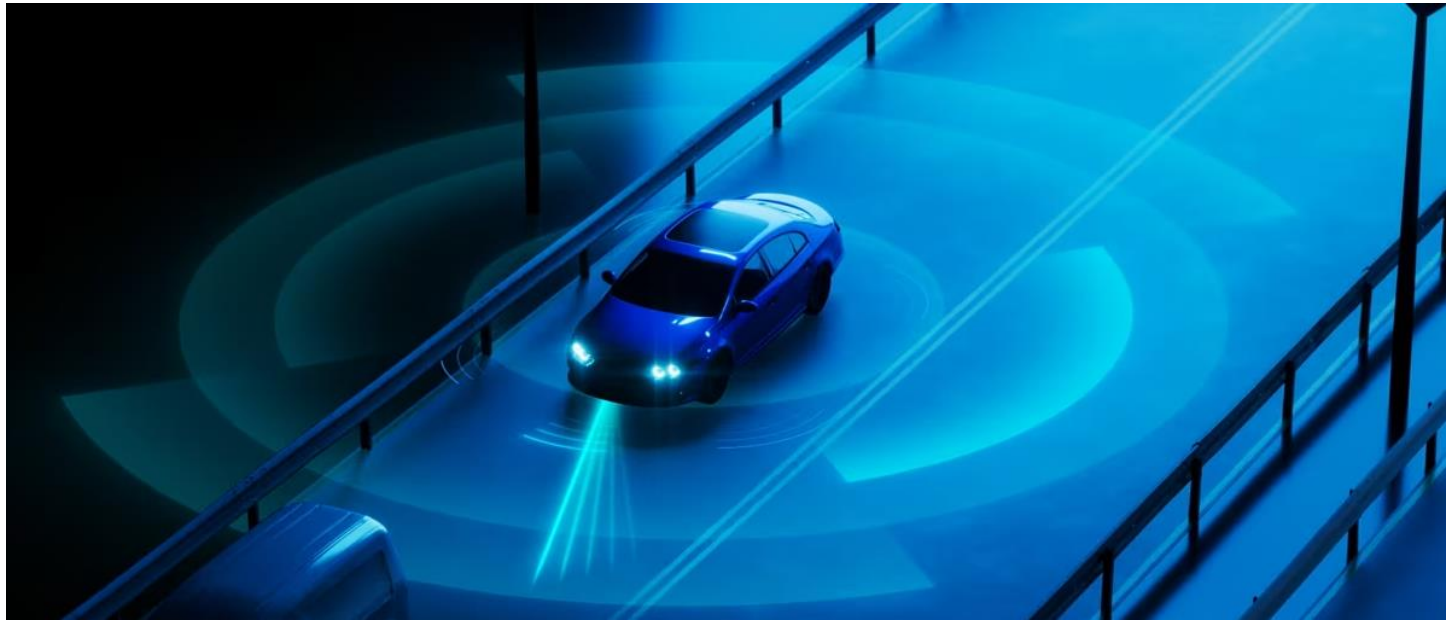
Perfectly linear modulation

Tunable self-injection locked laser



Kippenberg, *Nature* (2020): doi.org/10.1038/s41586-020-2239-3
Kippenberg, *Nature* (2023): doi.org/10.1038/s41586-023-05724-2

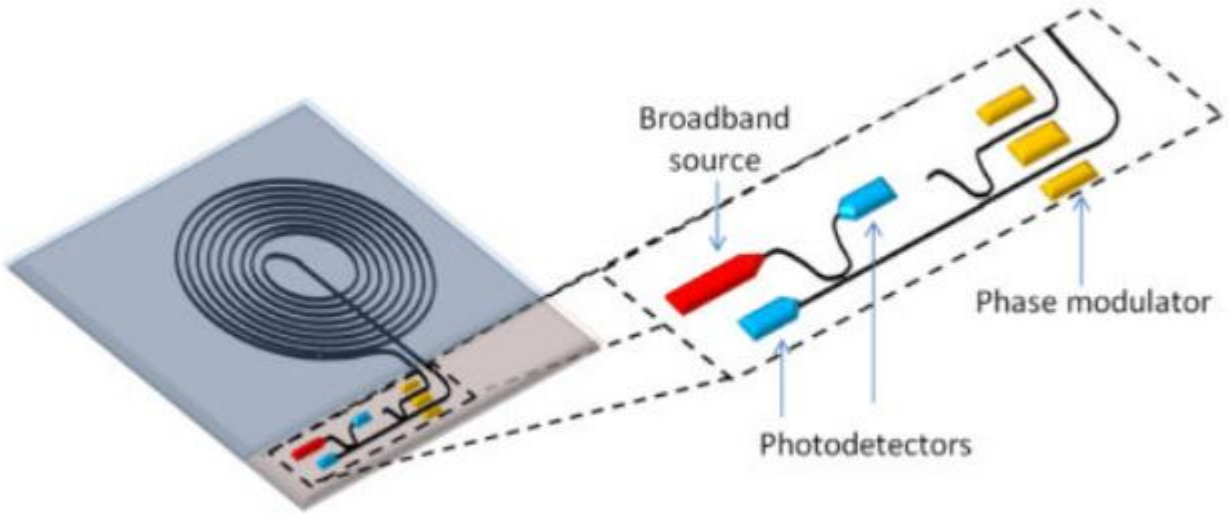




Integrated ring gyroscopes

Micro-optic gyroscopes

Different implementation use either phase or amplitude modulation



S. Srinivasan et. al, *Opt. Express* (2014): doi.org/10.1364/OE.22.024988

mermig
modular cmos photonic
integrated micro-gyroscope

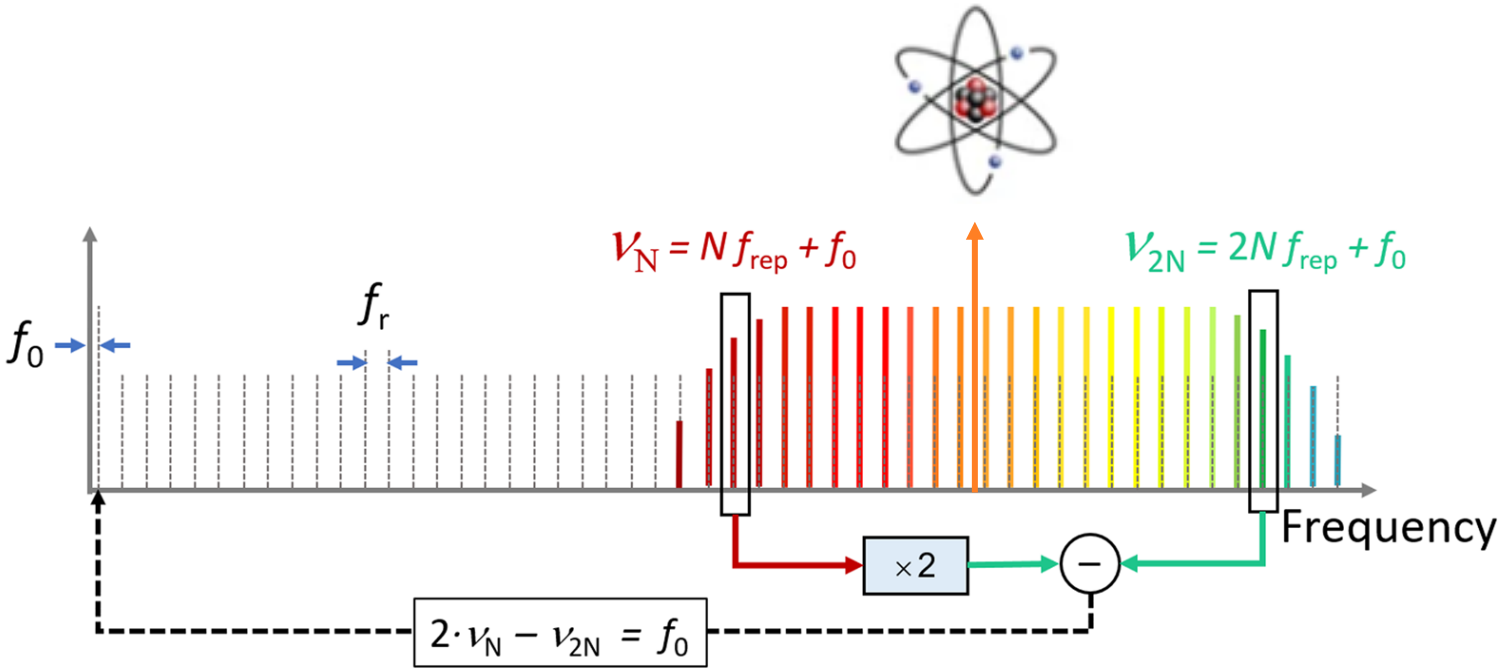
DAS Photonics

On-Chip Optical Clocks

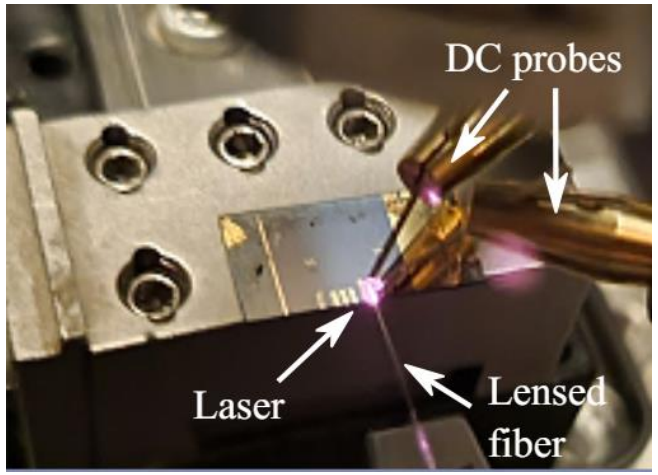
Components needed:

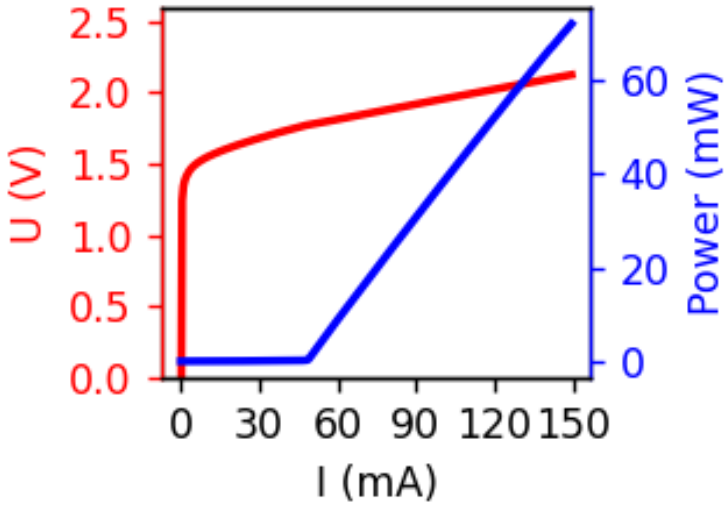
- Comb laser

Stable Mode-Locked Lasers on-chip



GaAs laser diodes transfer printed on silicon (800 nm / 100 mW)





On-Chip Optical Clocks

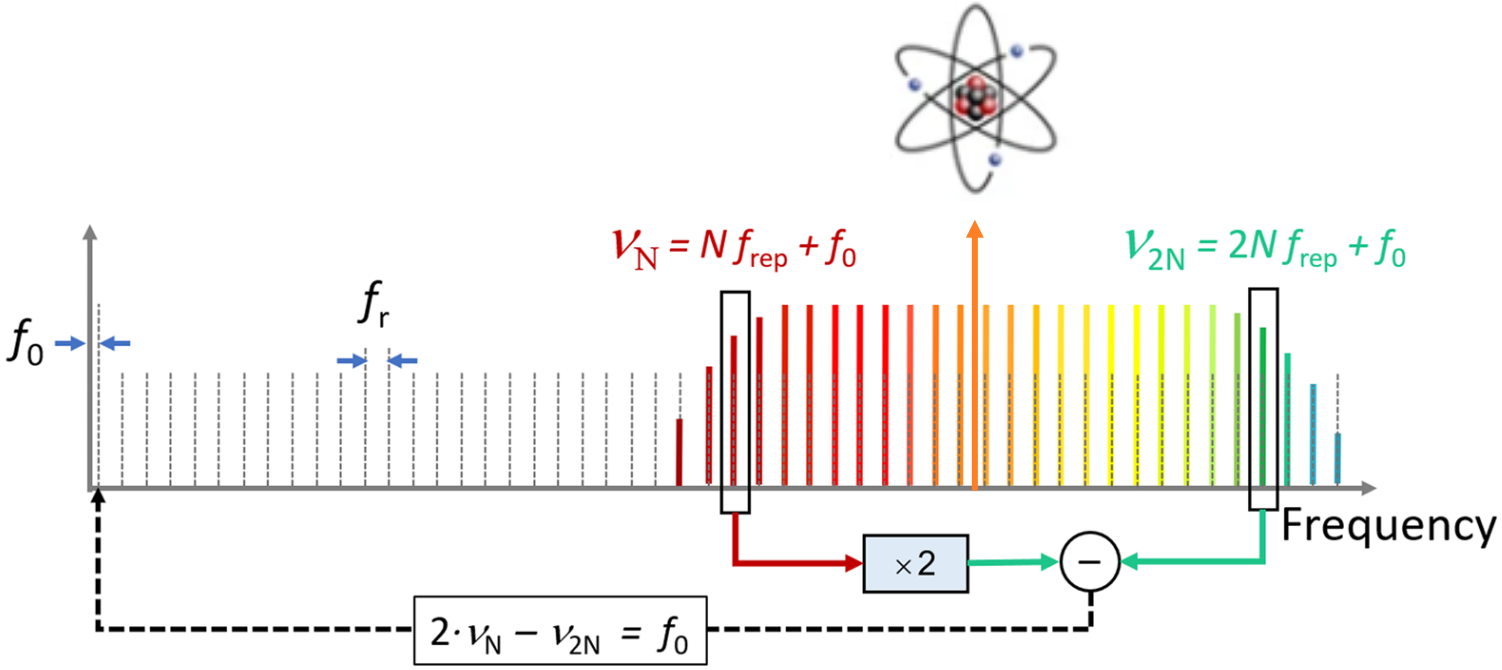
Components needed:

- Comb laser
- Frequency doubler

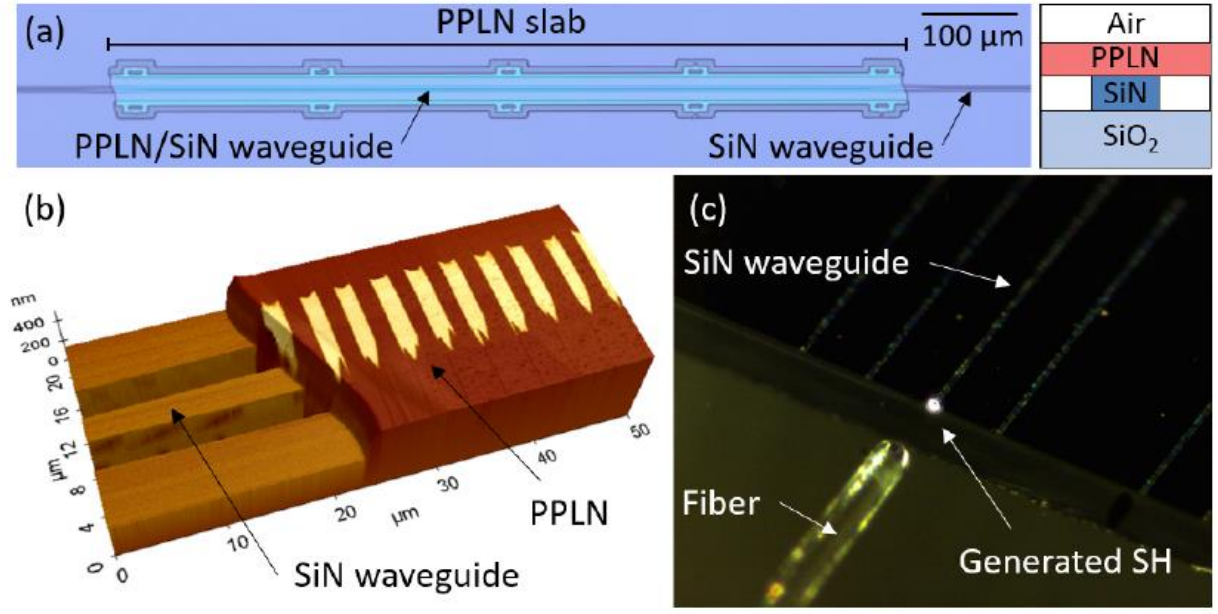
Efficient SHG

PPLN transfer printed coupons

Engineering Quasi-Phase matching



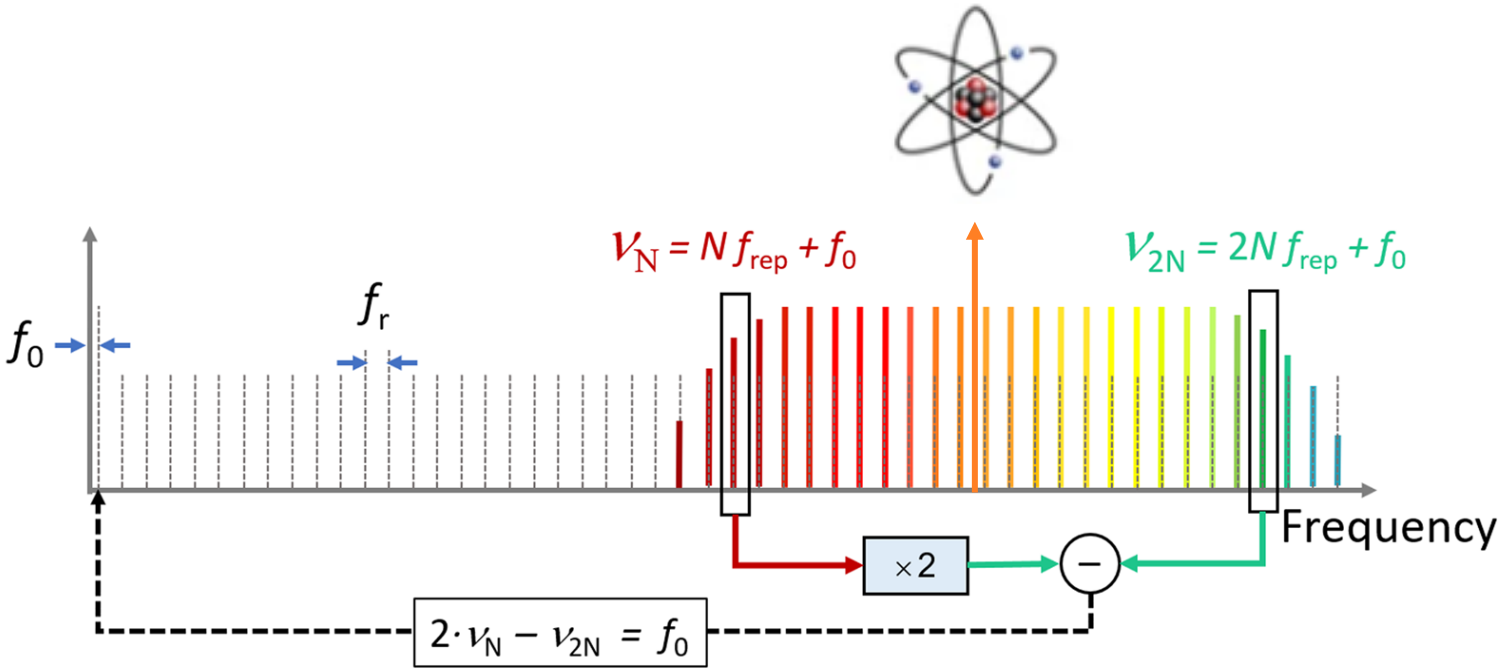
Periodically-poled lithium niobate transfer printed on silicon nitride



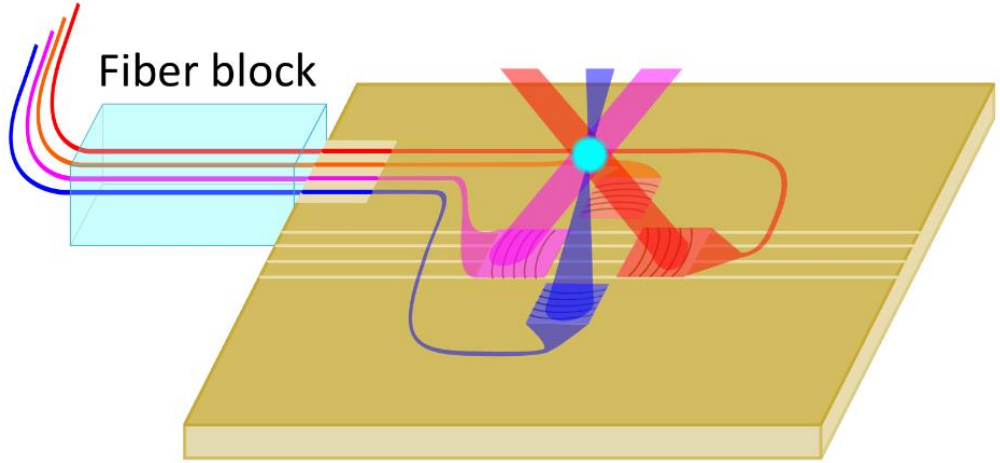
On-Chip Optical Clocks

Components needed:

- Comb laser
- Frequency doubler
- Narrow-linewidth laser locked to atomic resonance
- Atomic reference



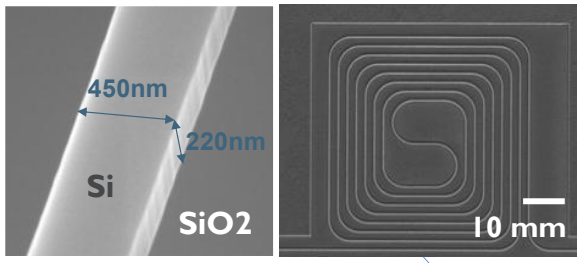
Chiaverini, *Nature* (2020): doi.org/10.1038/s41586-020-2811-x



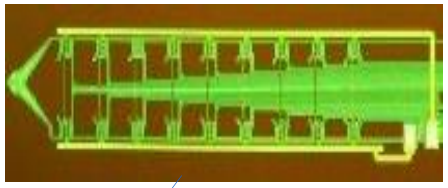
Imec Silicon Photonics Technology

iSiPP200N

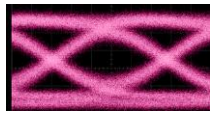
High-density Si Waveguides *(0.5-2dB/cm)*

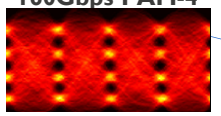


Silicon WDM filters

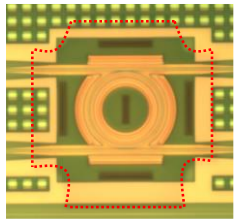


56-160Gbps
Silicon Ring Modulator

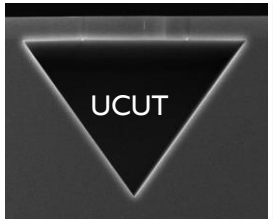




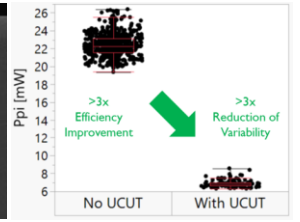
Y. Tong et al., PTL 2020



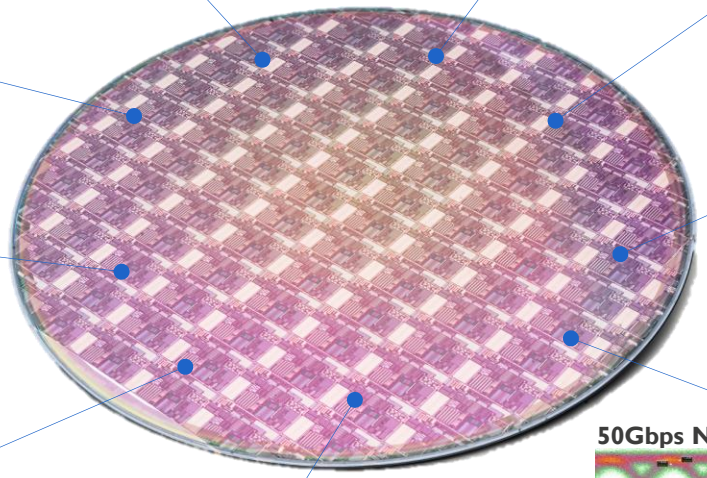
Efficient Thermo-Optic Phase Tuners



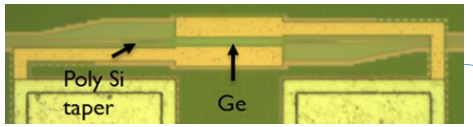
Undercut

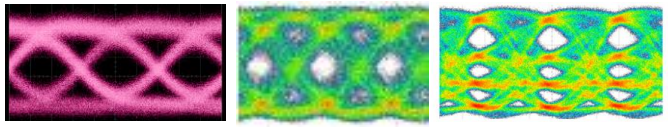


Low Thermo-Optic Powe Consumption

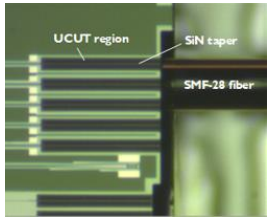


56-128Gbps GeSi Electro-Absorption Modulator

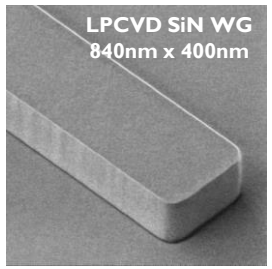


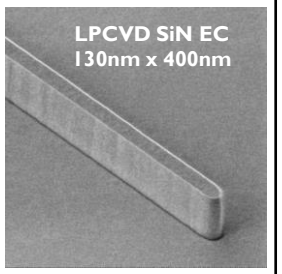


Integrated LPCVD SiN Waveguides

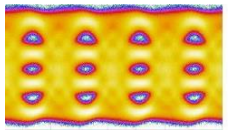


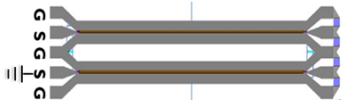
SiN Edge Coupler 9um MFD (<3dB)

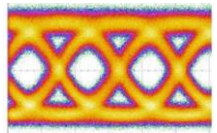




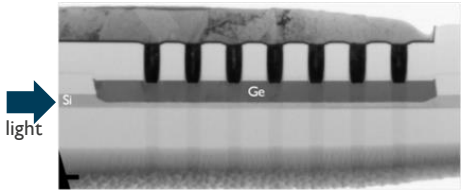
56-106Gbps Silicon Mach-Zehnder Modulator

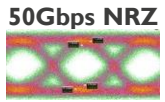


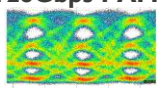


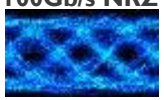


56-128Gbps Ge Photodetector

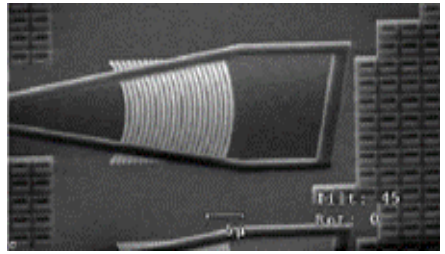




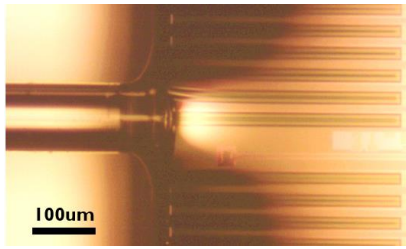




SMF Grating Coupler *(<2dB)*



High-NA *(<2dB)* **&**
SMF Edge Couplers *(<3dB)*



Fully Integrated Silicon Photonics Platform for 1310nm/1550nm Wavelengths

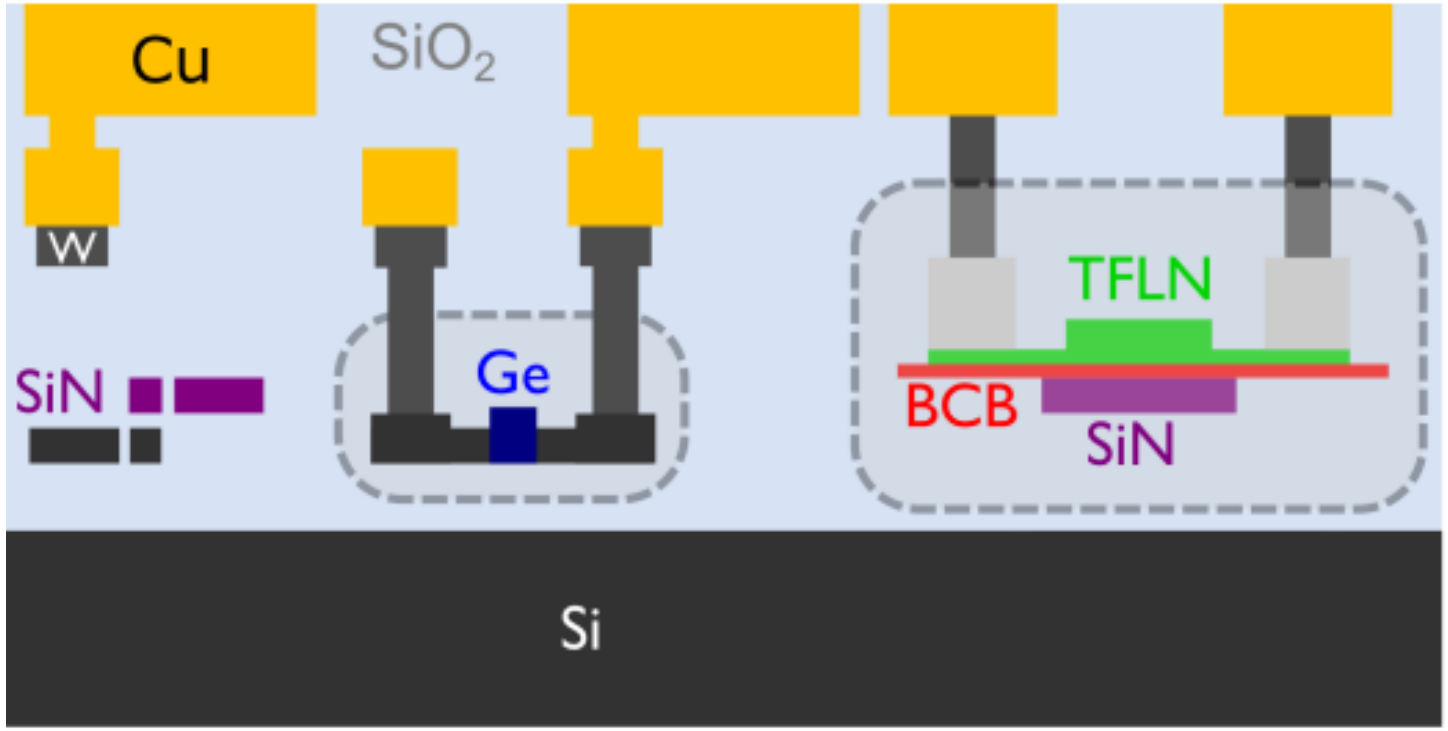
imec (and many others) now offer fairly complete silicon photonics platforms

- 56Gb/s+ (Ge)Si Modulators and Ge(Si) Photodetectors

12

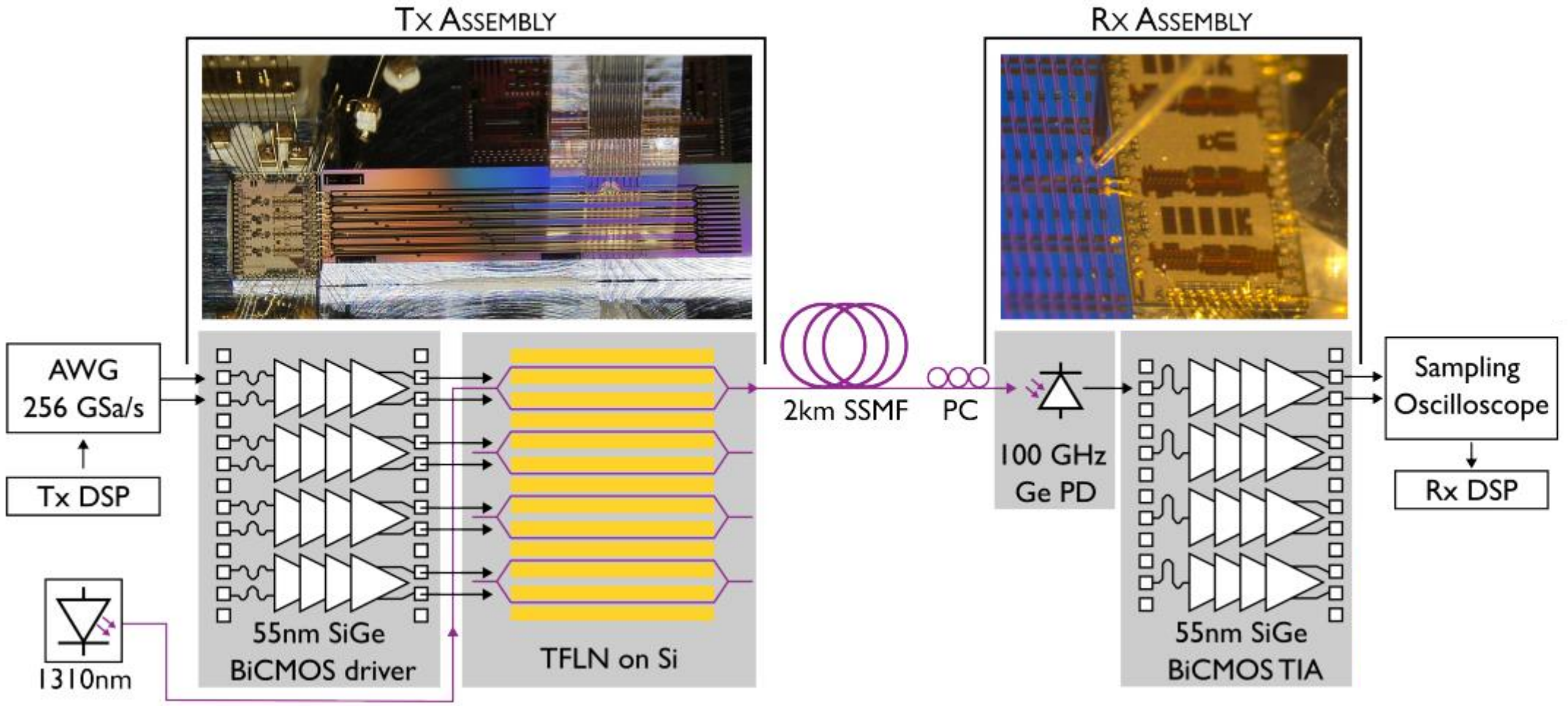
Germanium Photodetectors are part of the SiPho PDK

Potentially leading to the co-integration of LN and High speed LN modulators

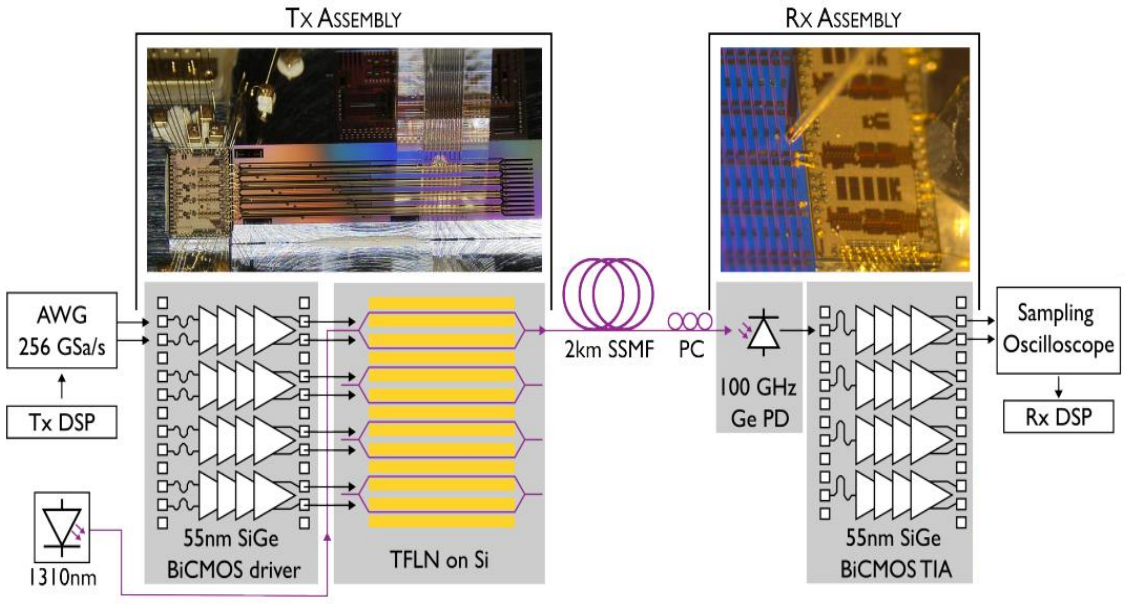


Making a full link based on (heterogeneous) Silicon Photonics

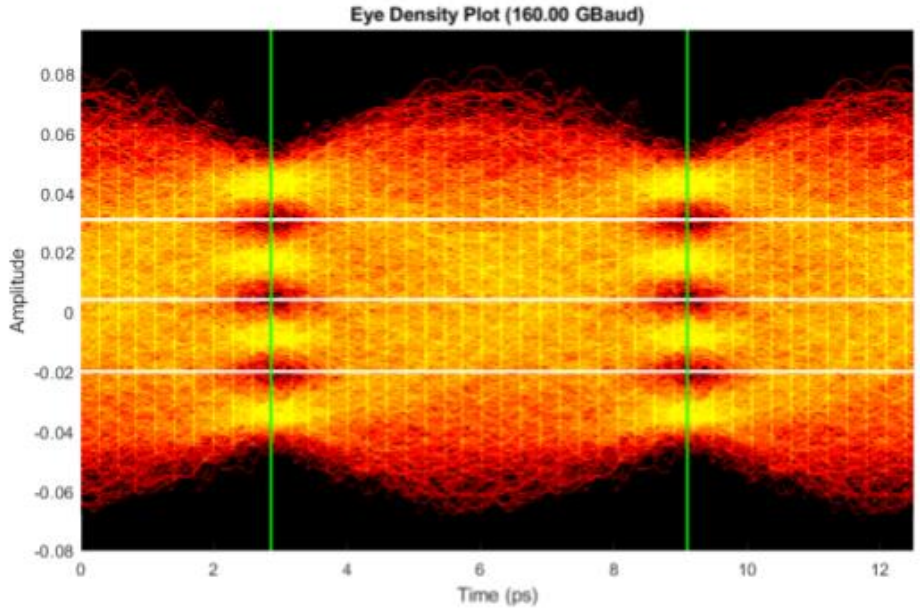
Using an EIC driver, a heterogeneous PIC, a SiPho receiver and a EIC TIA

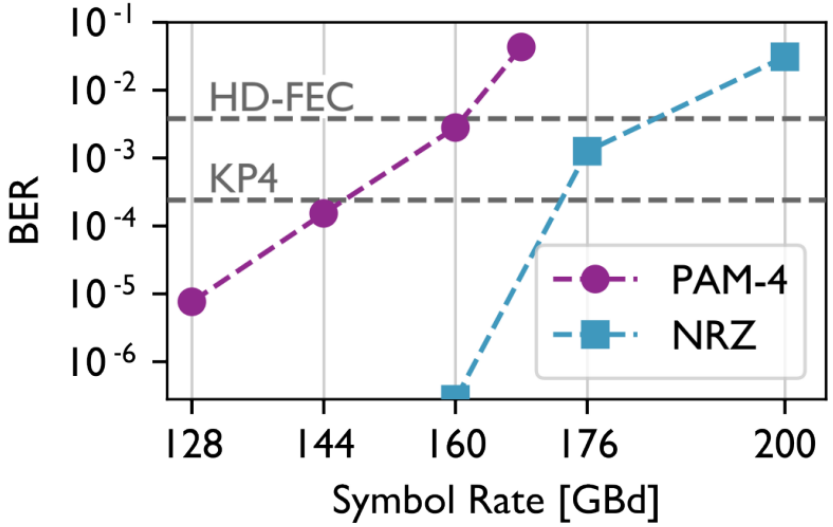


High Speed link allows for 320 Gbit/s link



The efficiency of the link:4 pJ/bit



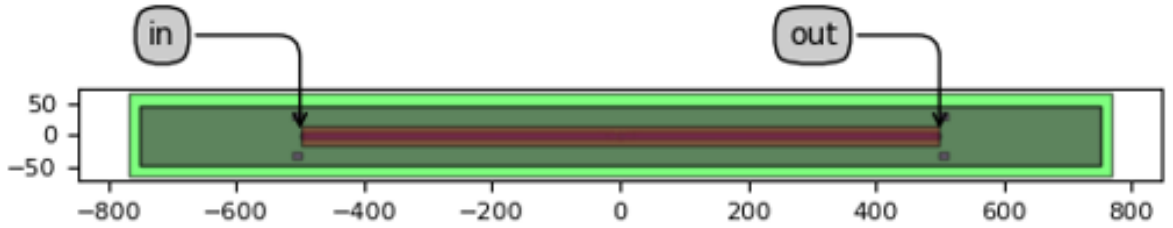


WP2 : PDK tool and guidelines

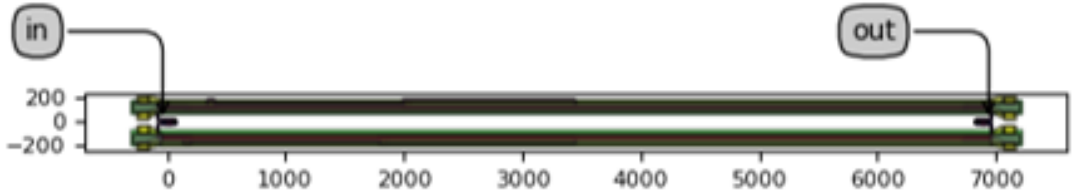
Attached is a pdk section with user guidelines on the different parameters of both Lithium niobate coupons stand alone and Mach Zehnder Modulators. Some of the information here references terms from the imec PDK.

Separately attached is a copy of the PDK used for the imec run on which we are printing. This is slightly simplified from the full ISIPP200N platform of imec and should be considered Proprietary Information but contains all other components of the platform with their rules and guidelines.

LN_Coupon_1550



MZM



WP2: IMEC ISIPP200N PDK available

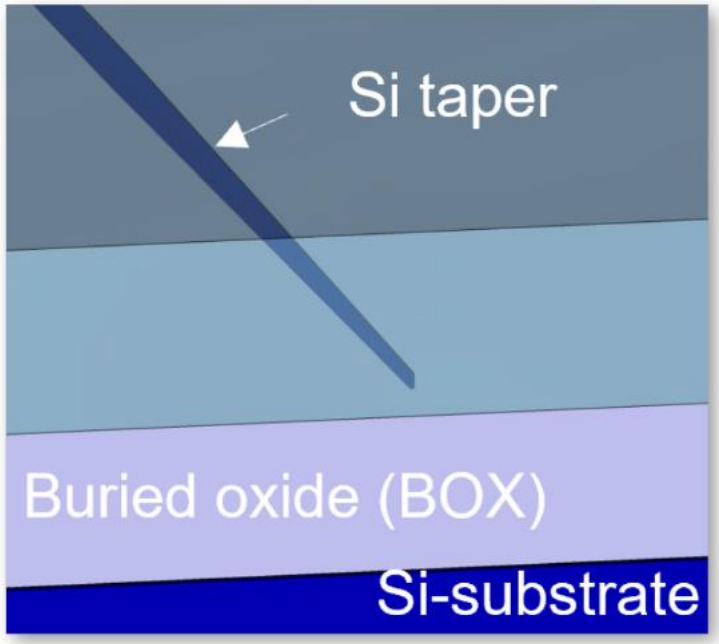
Edge Coupler <3 dB:

Fiber – chip coupling @ 1550 nm

1x2 and 2x2 MMI splitters in Silicon:

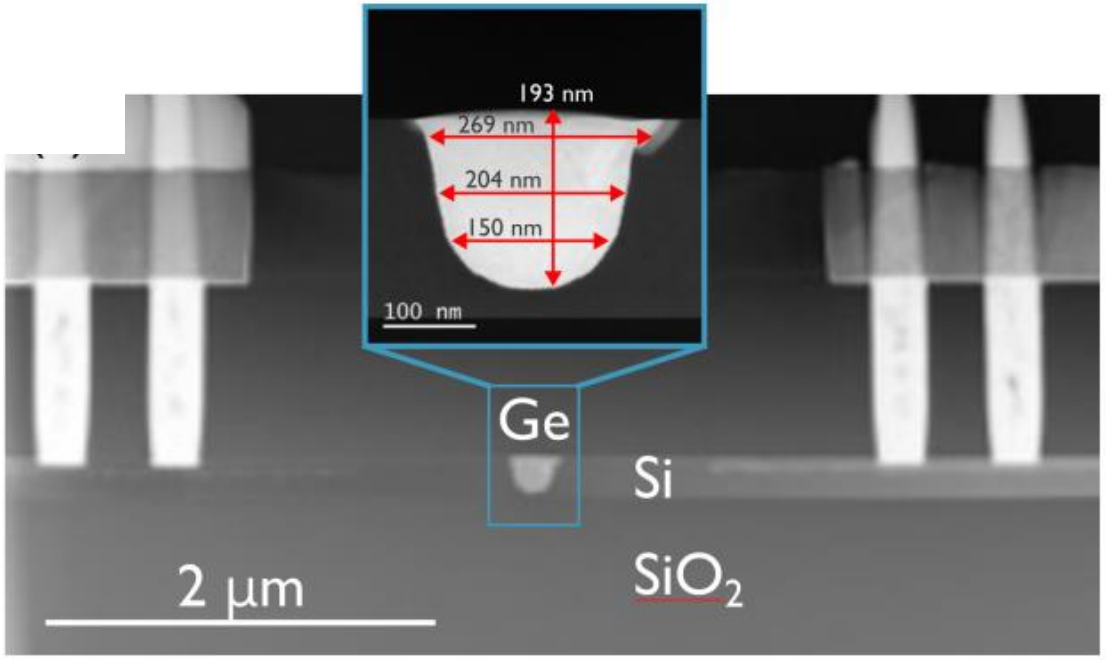
Very balanced

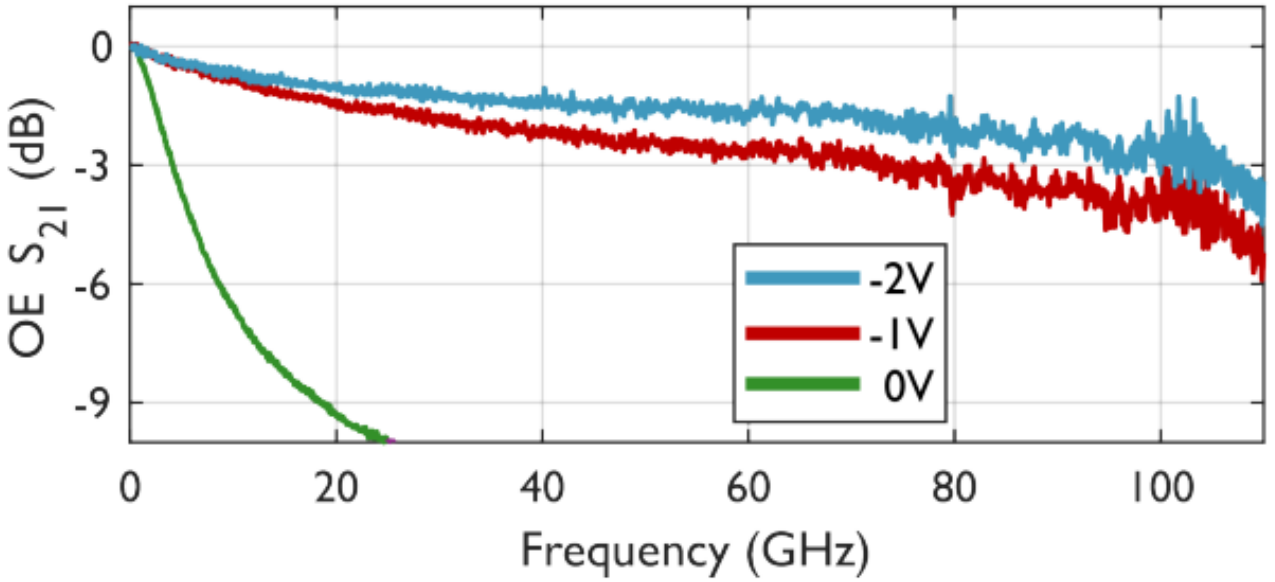
Minimal insertion loss



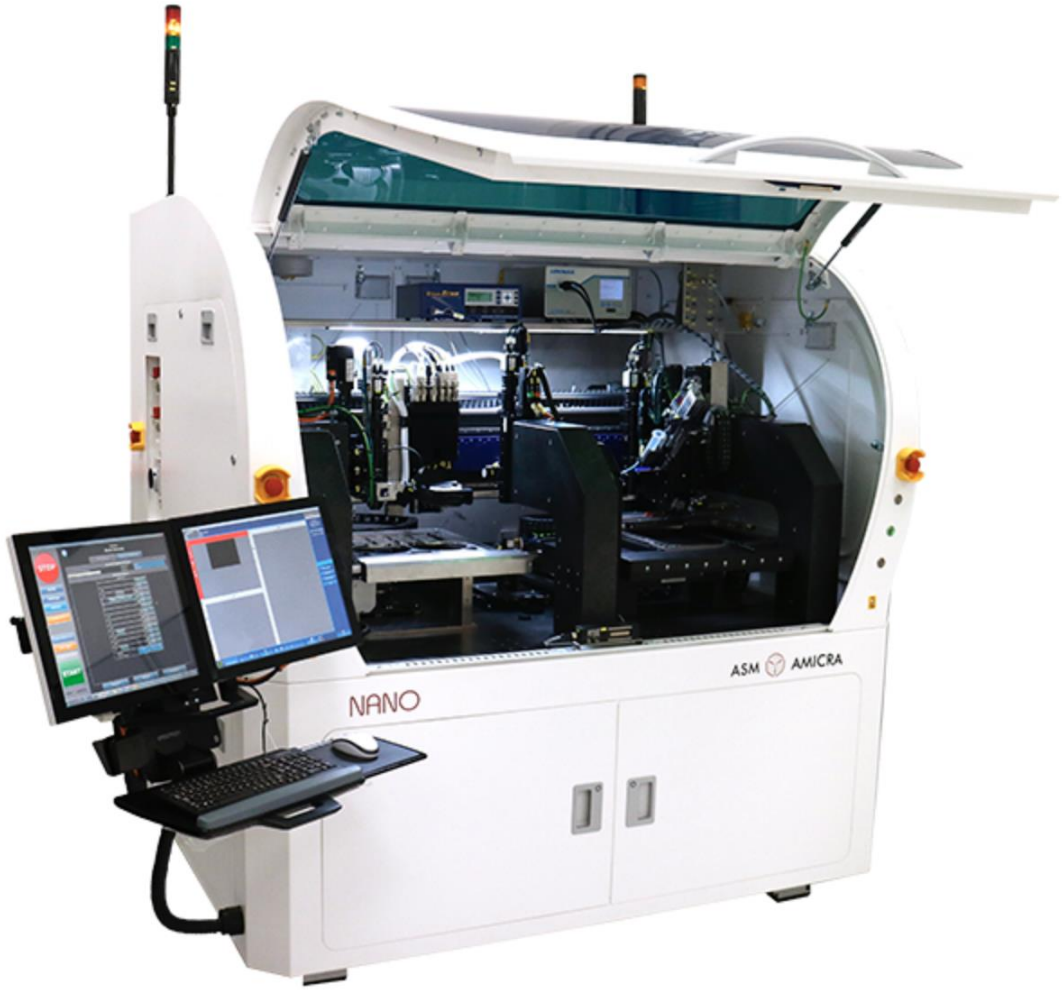
Germanium Photodetectors on a Silicon Photonic platform

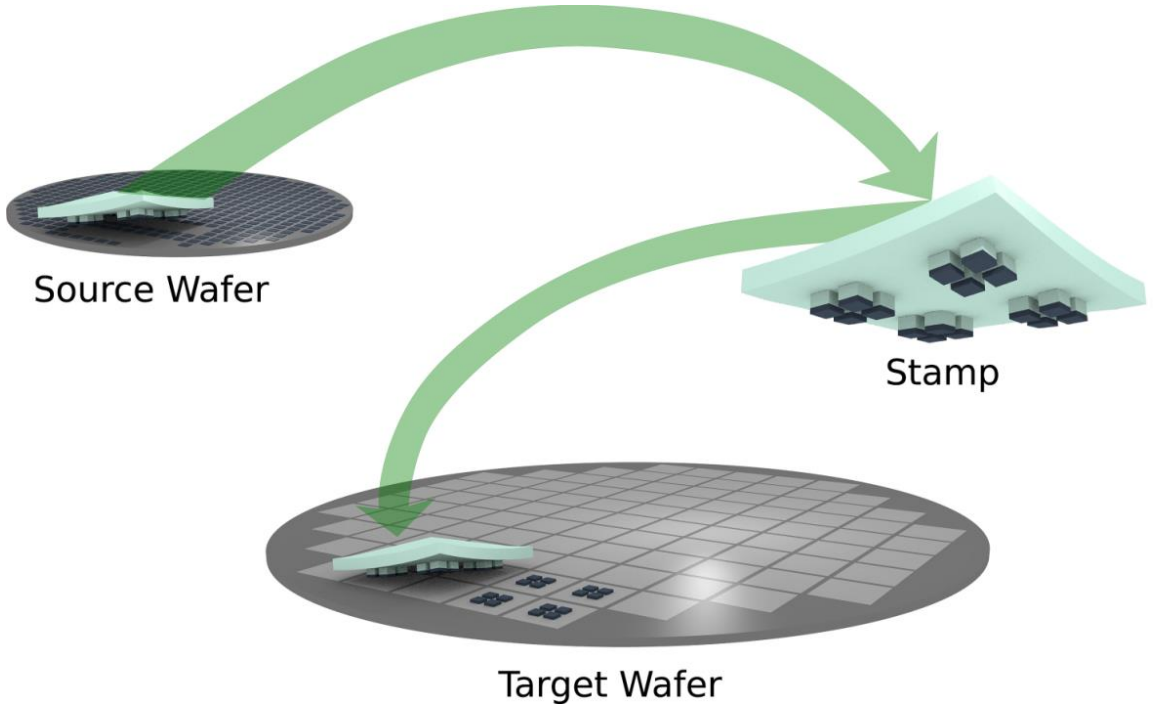
Bandwidth >100 GHz





Micro-transfer printing





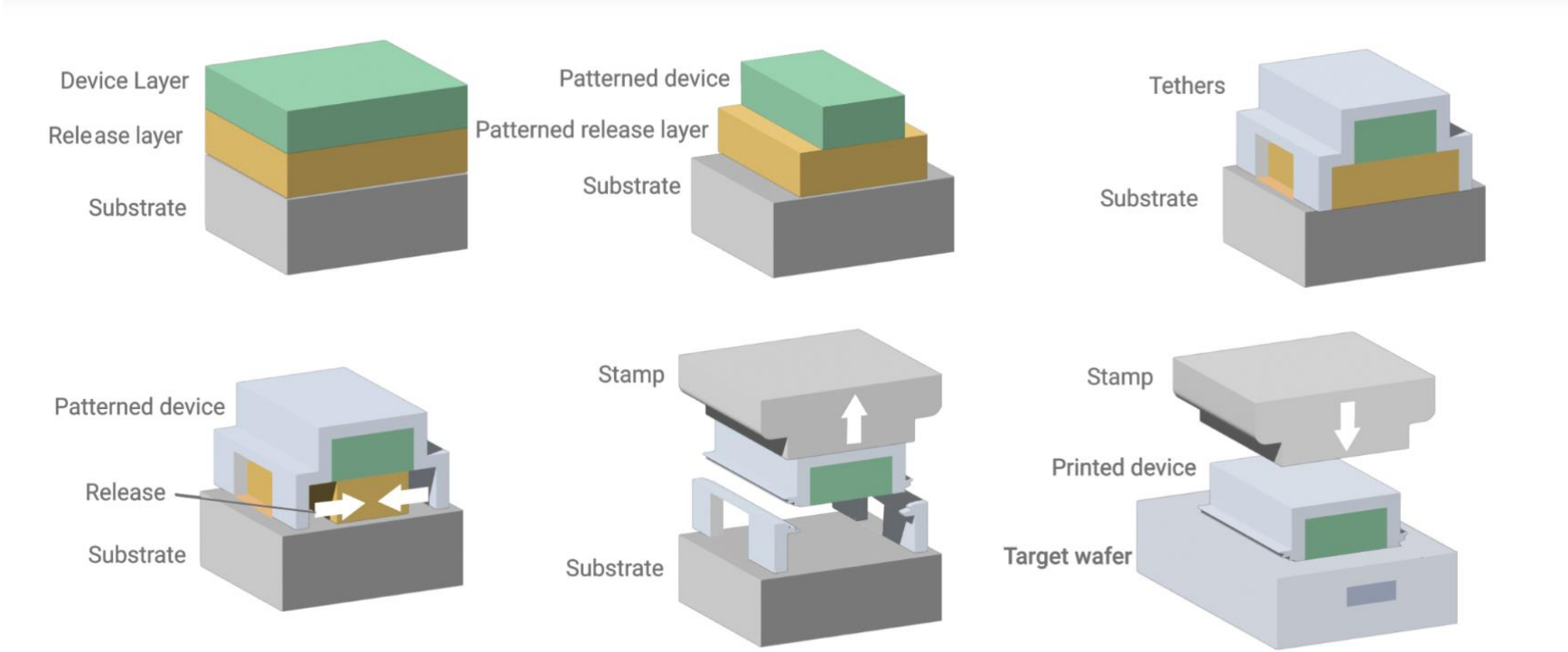
New tools: position tolerance of +/- 0.5 µm at 3σ in medium arrays (2cm x 2cm) – 1 print cyle <60 sec

GHENT UNIVERSITY

What is transfer printing?

Micro-transfer printing basics

Device processing, release, pick-up & print



Any device or material that can be released from its substrate can be micro-transfer printed

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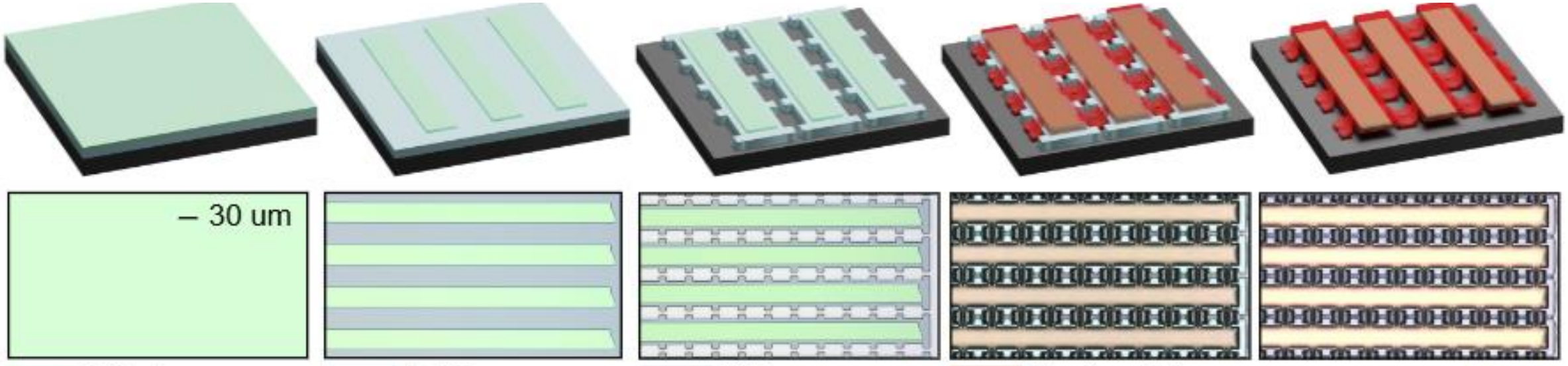
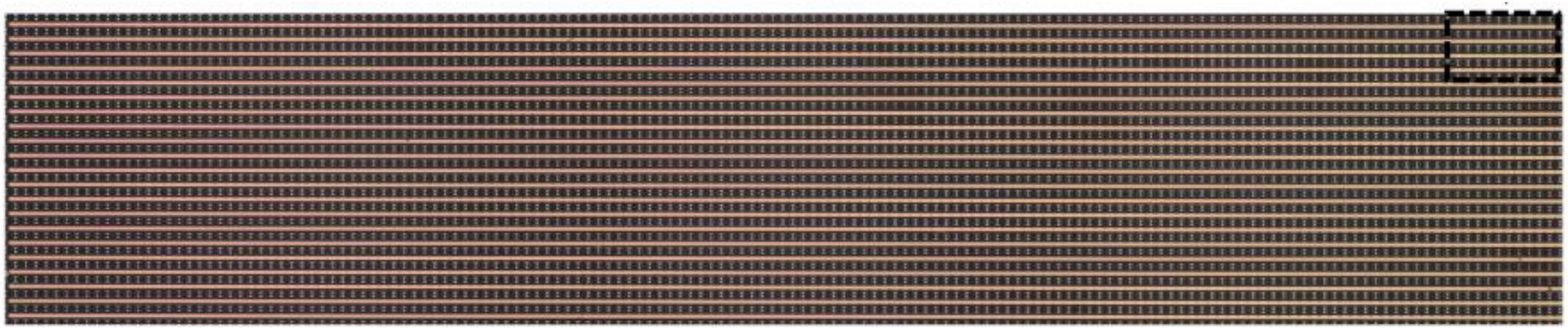
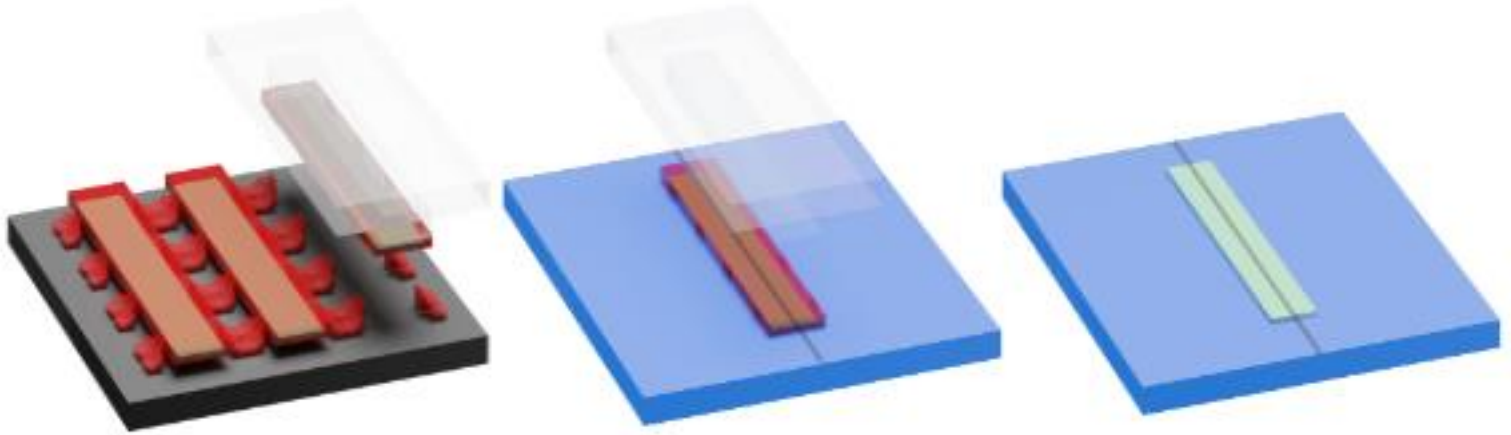
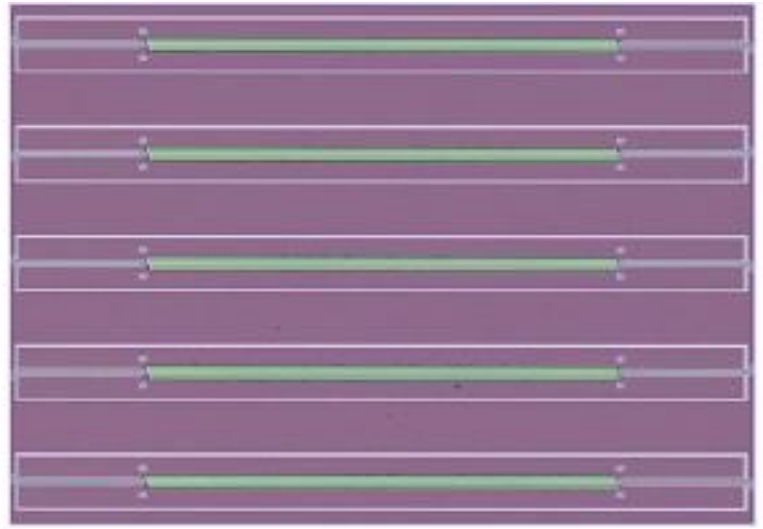
Micro-transfer printing: Technique to transfer(patterned) epi layers



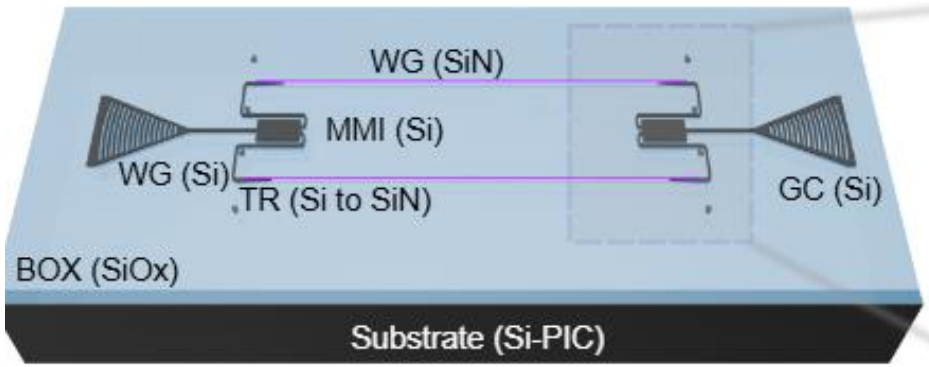
Micro-transfer printing: Technique to transfer(patterned) epi layers

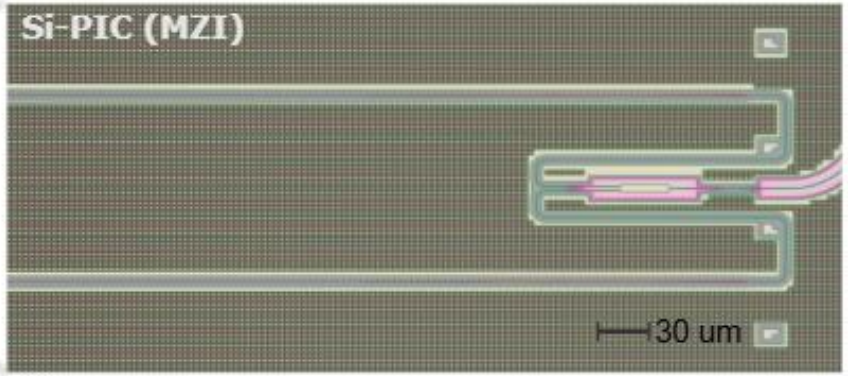


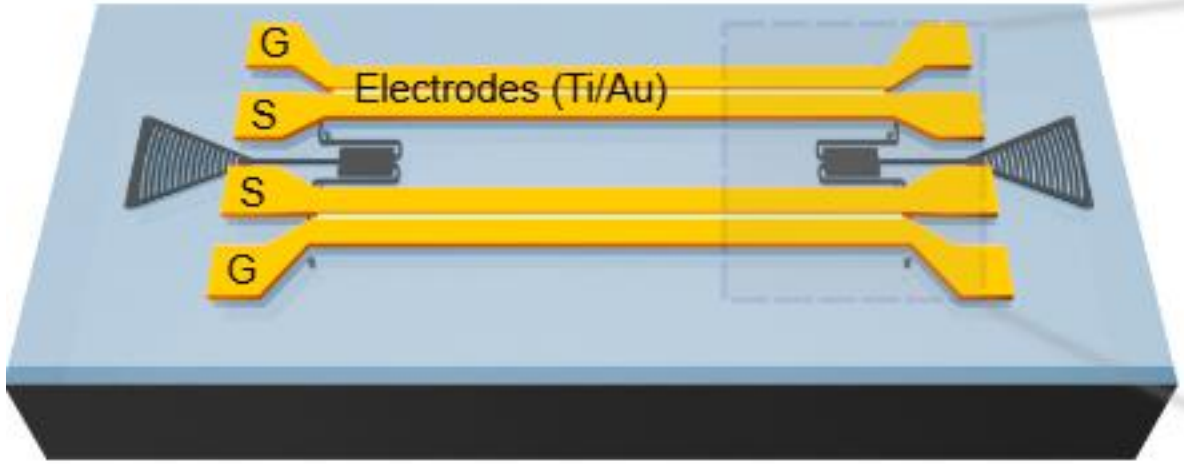


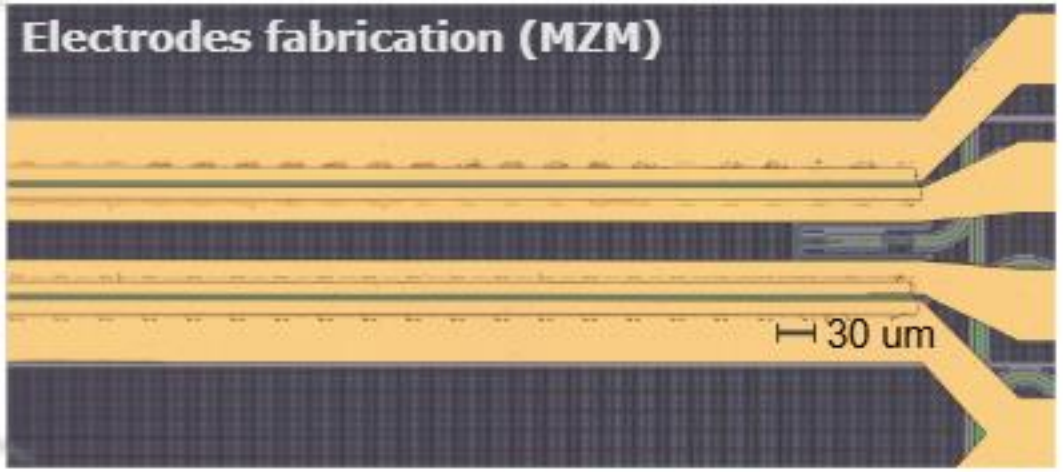


A 7mm long hybrid high-speed modulator on a silicon photonic platform



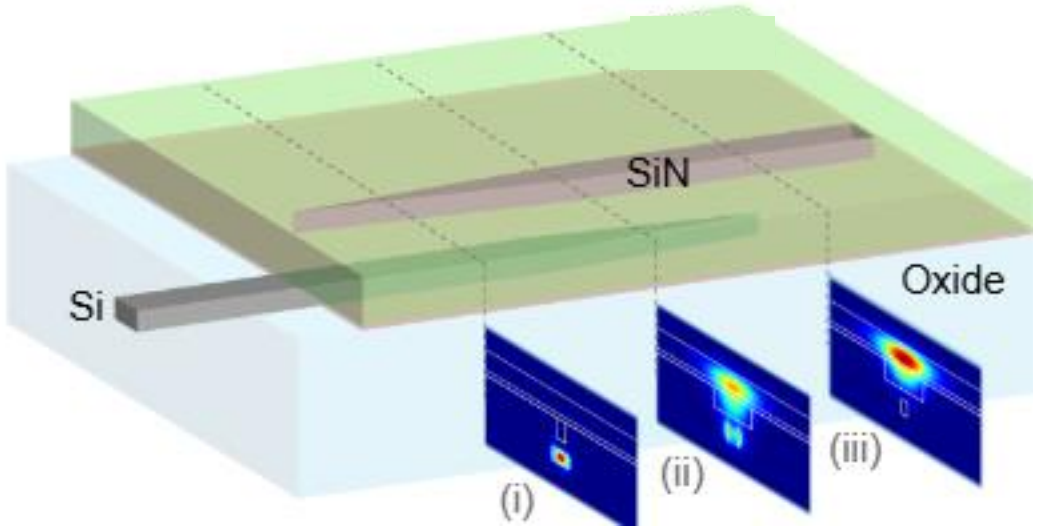


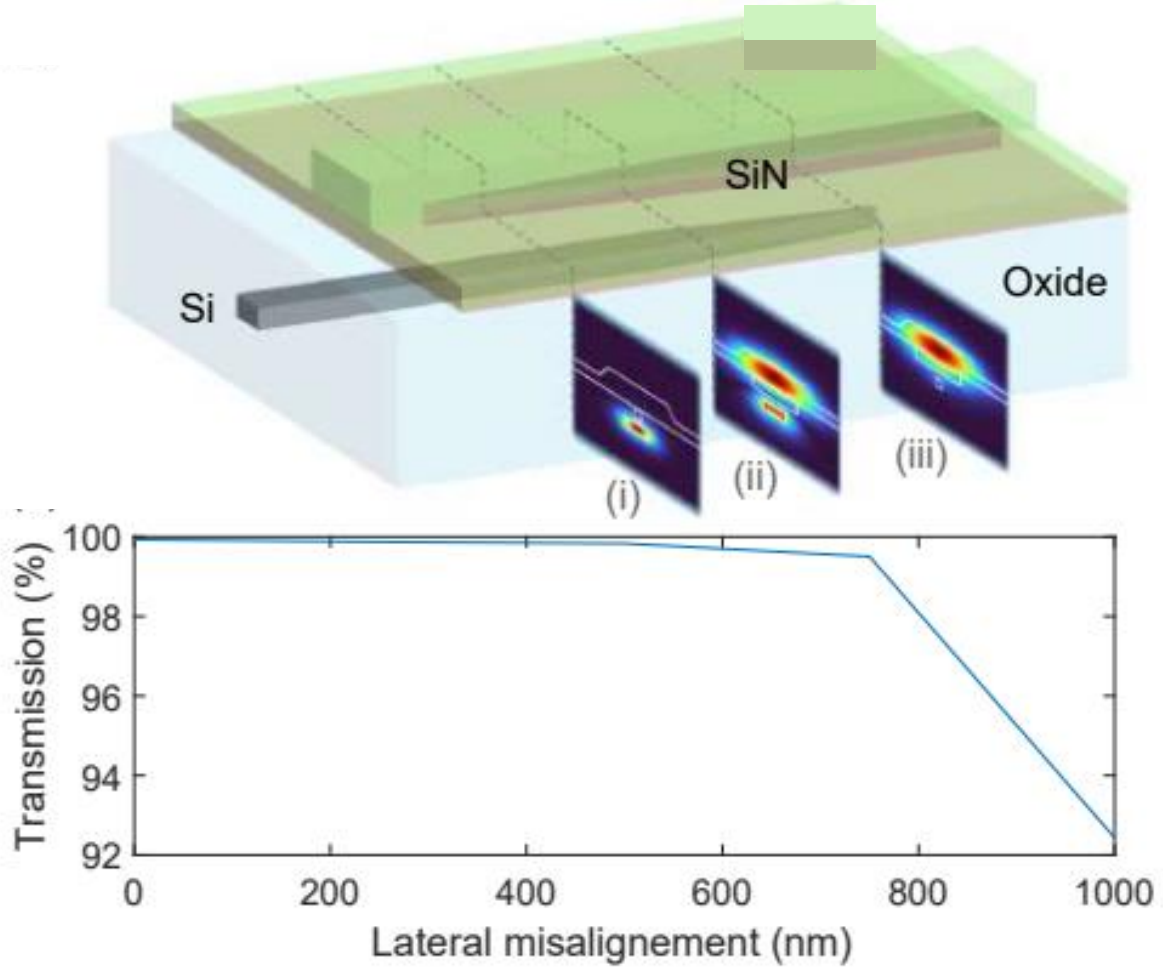




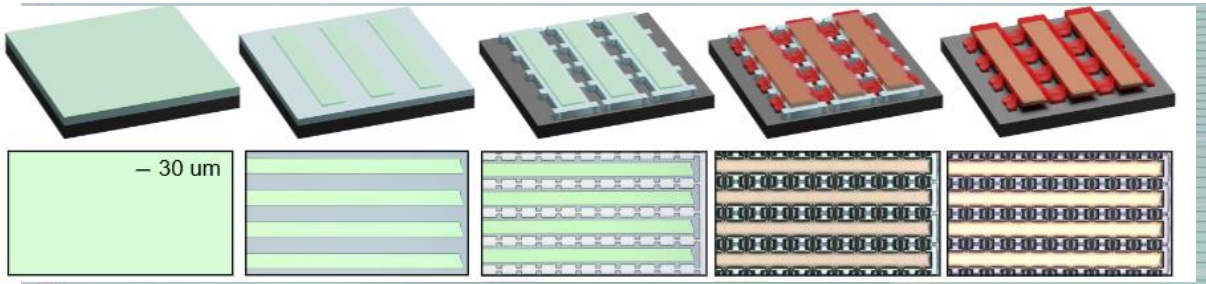
Hybrid modulators are limited in efficiency as the mode is not very well confined

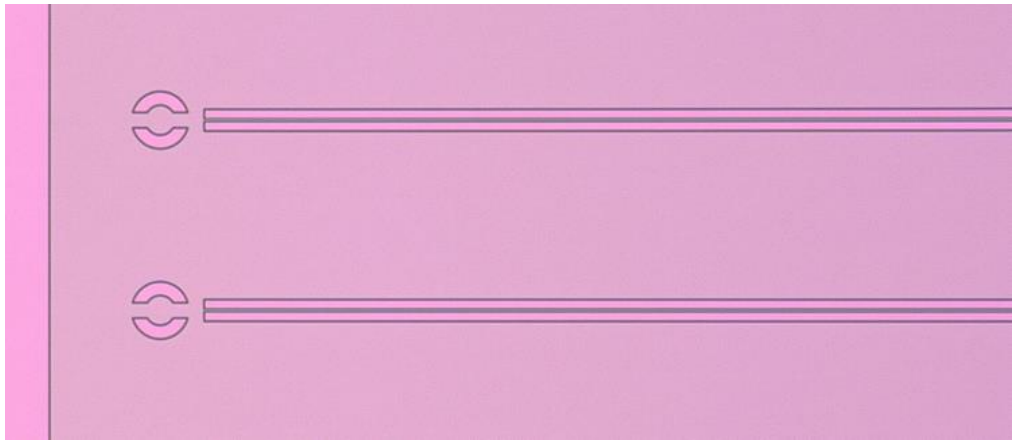
The quest for high confinement waveguides





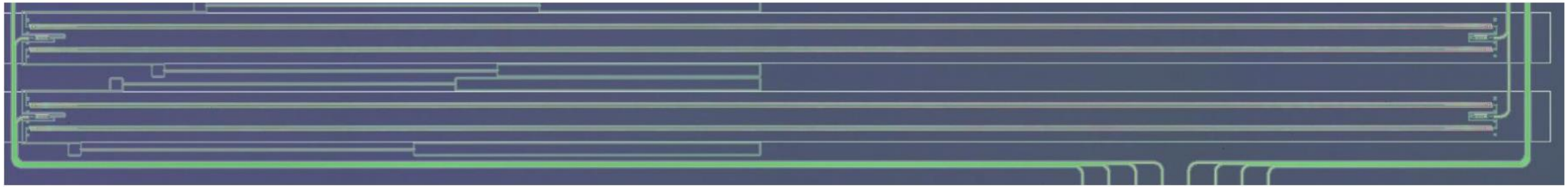
Higher confinement by using pre-patterned LN waveguides

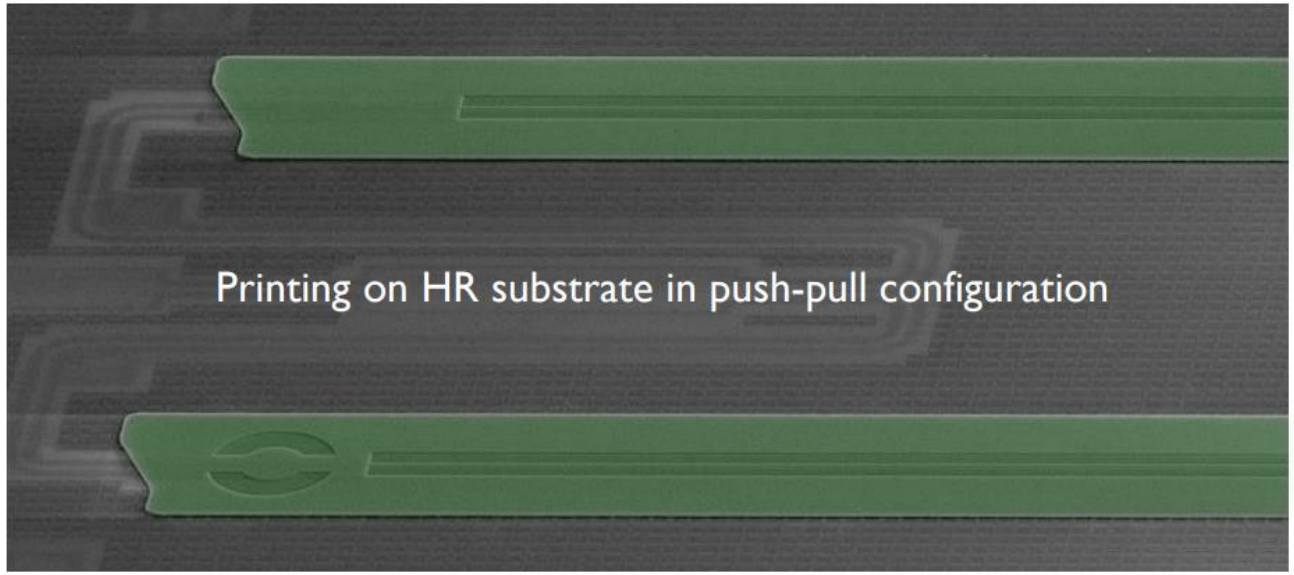


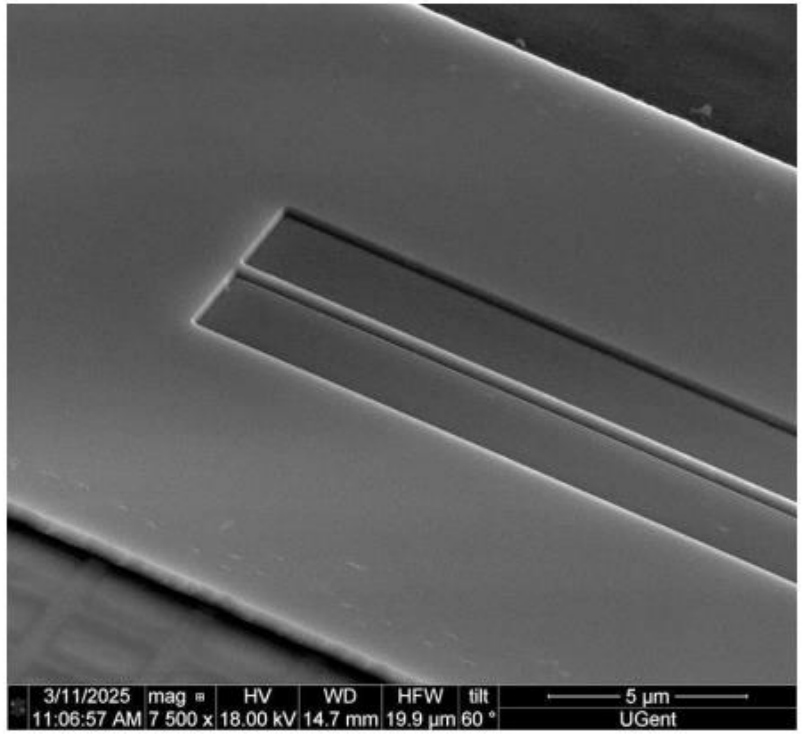


Printing of pre-patterned coupons

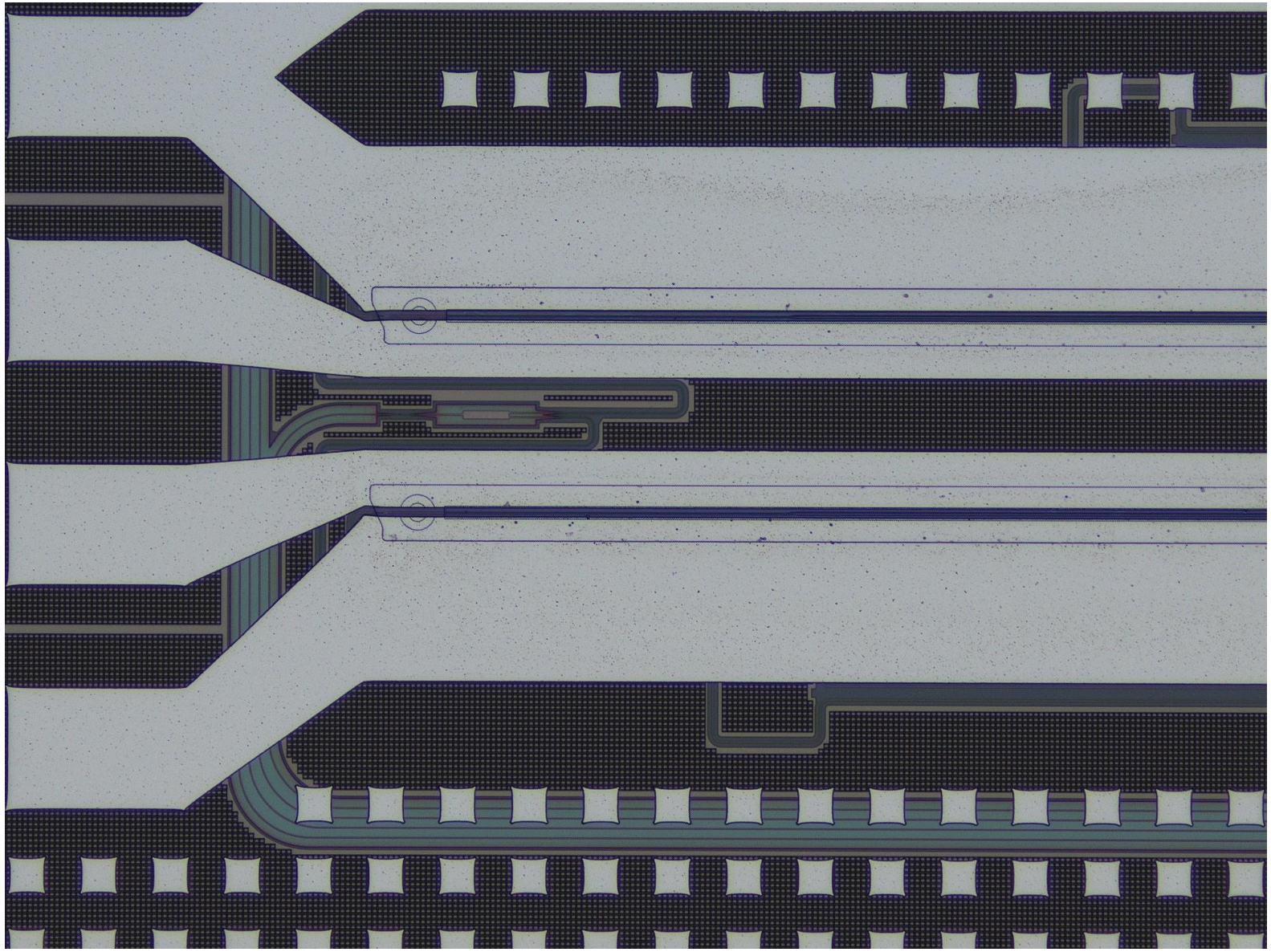
7 mm long patterned coupons have been printed on a silicon photonic wafer

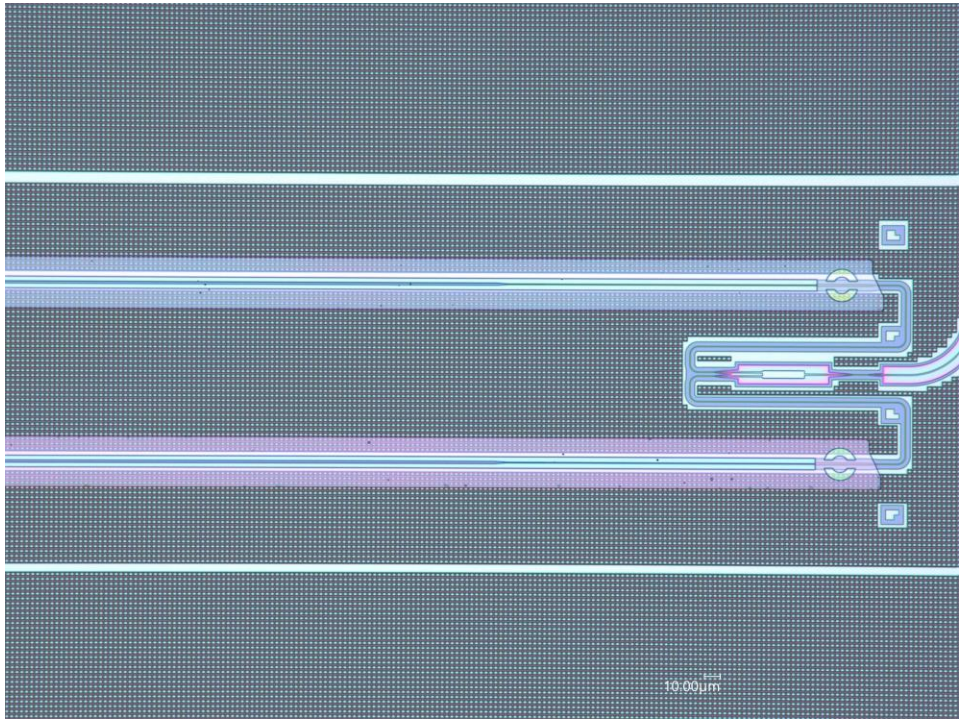




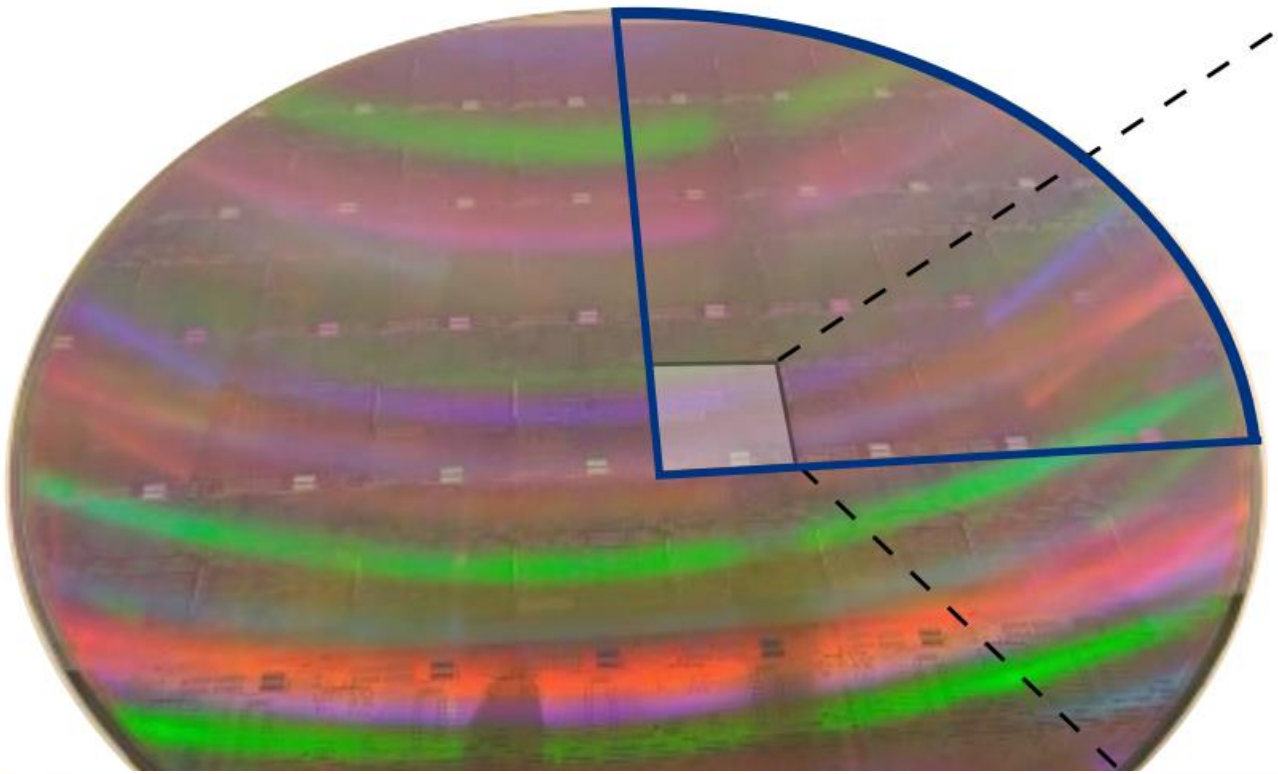


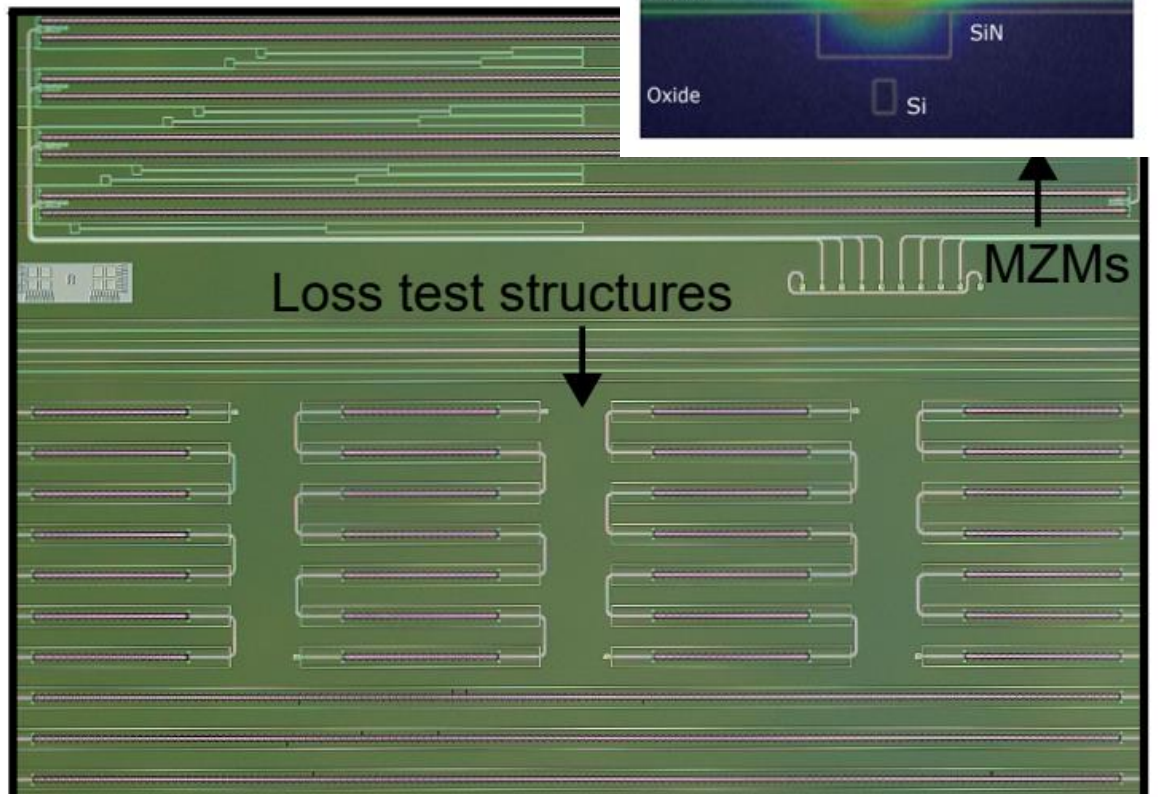
Fabrication and printing of 1 mm 1.2 mm

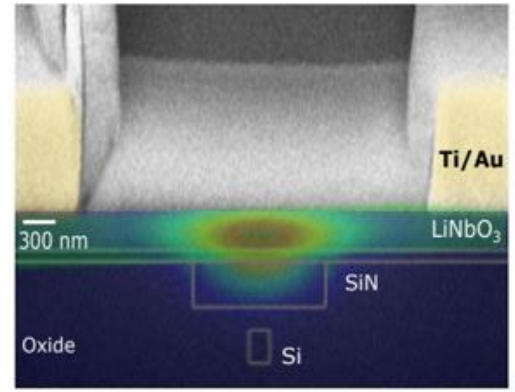


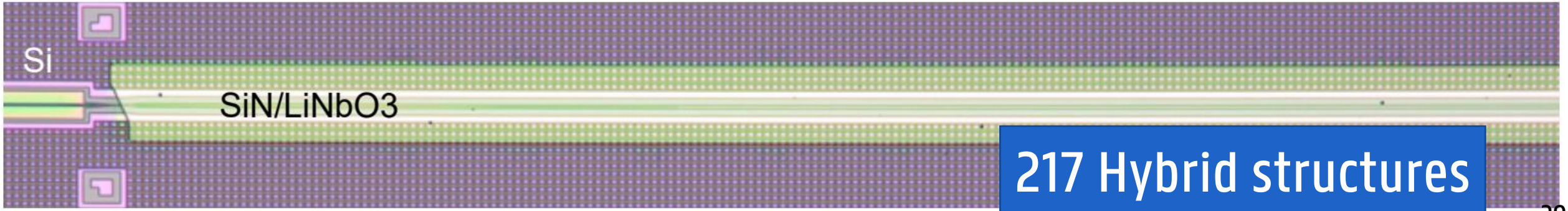


Fabrication of a wafer with test structures



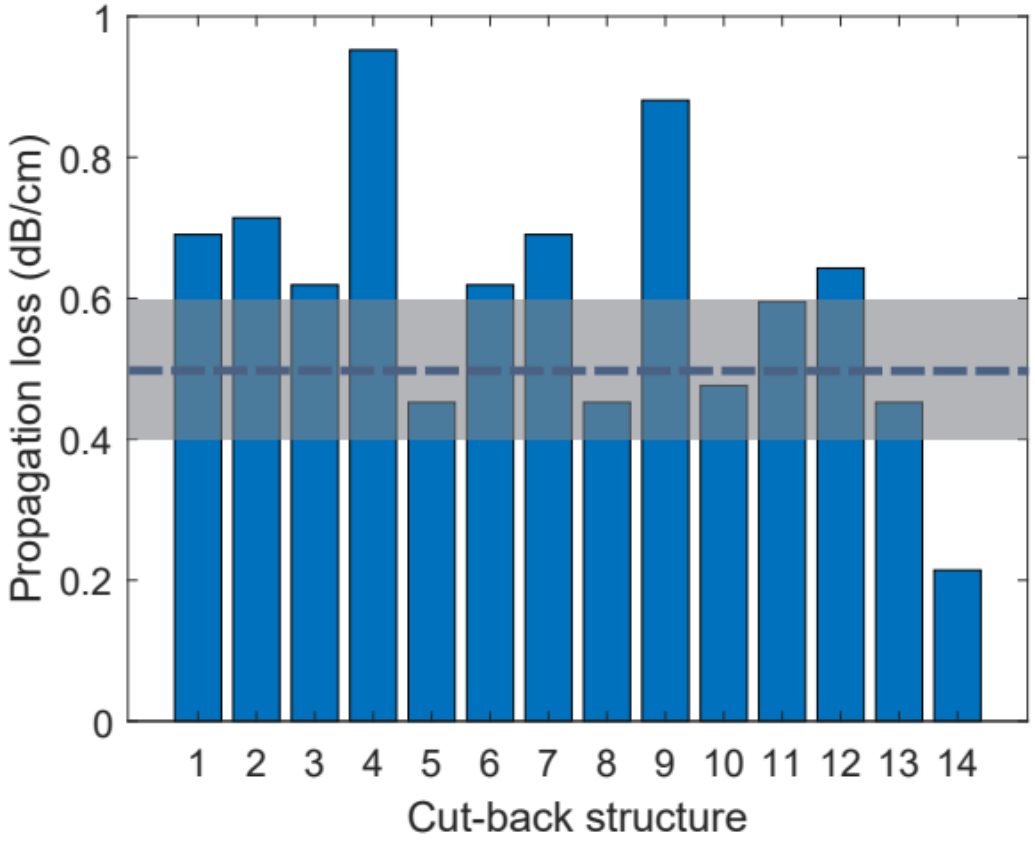


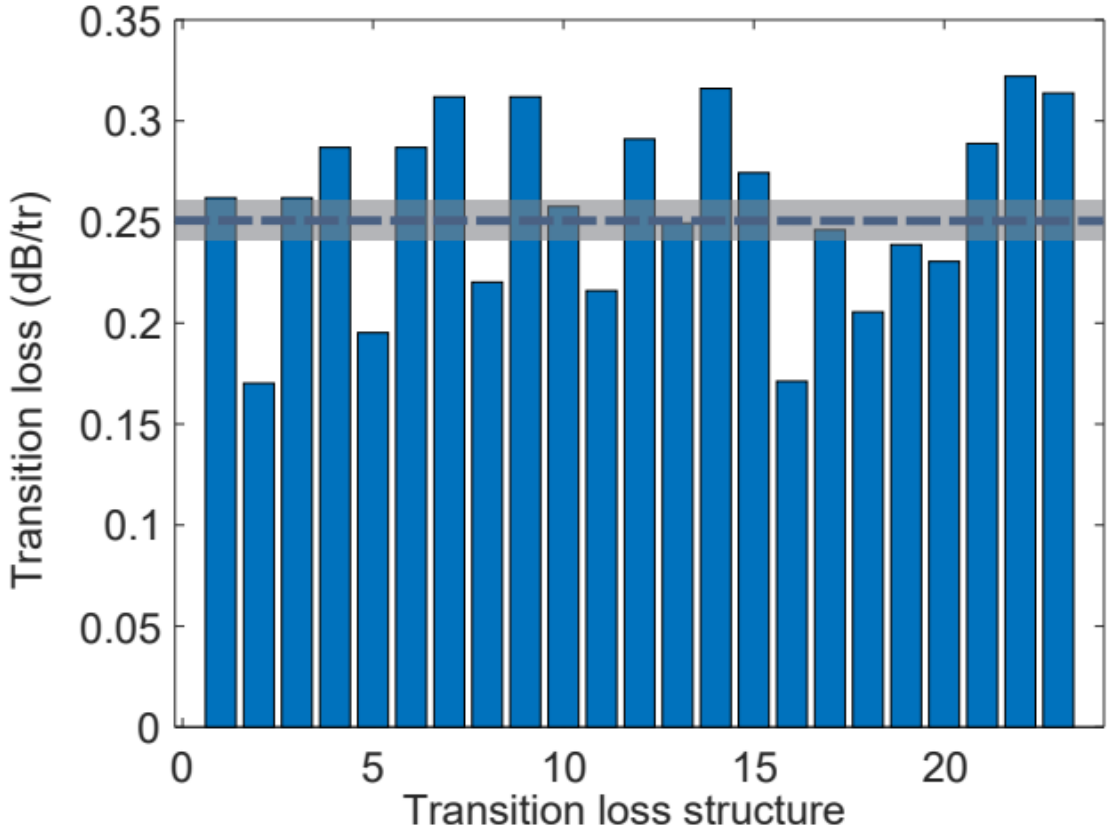




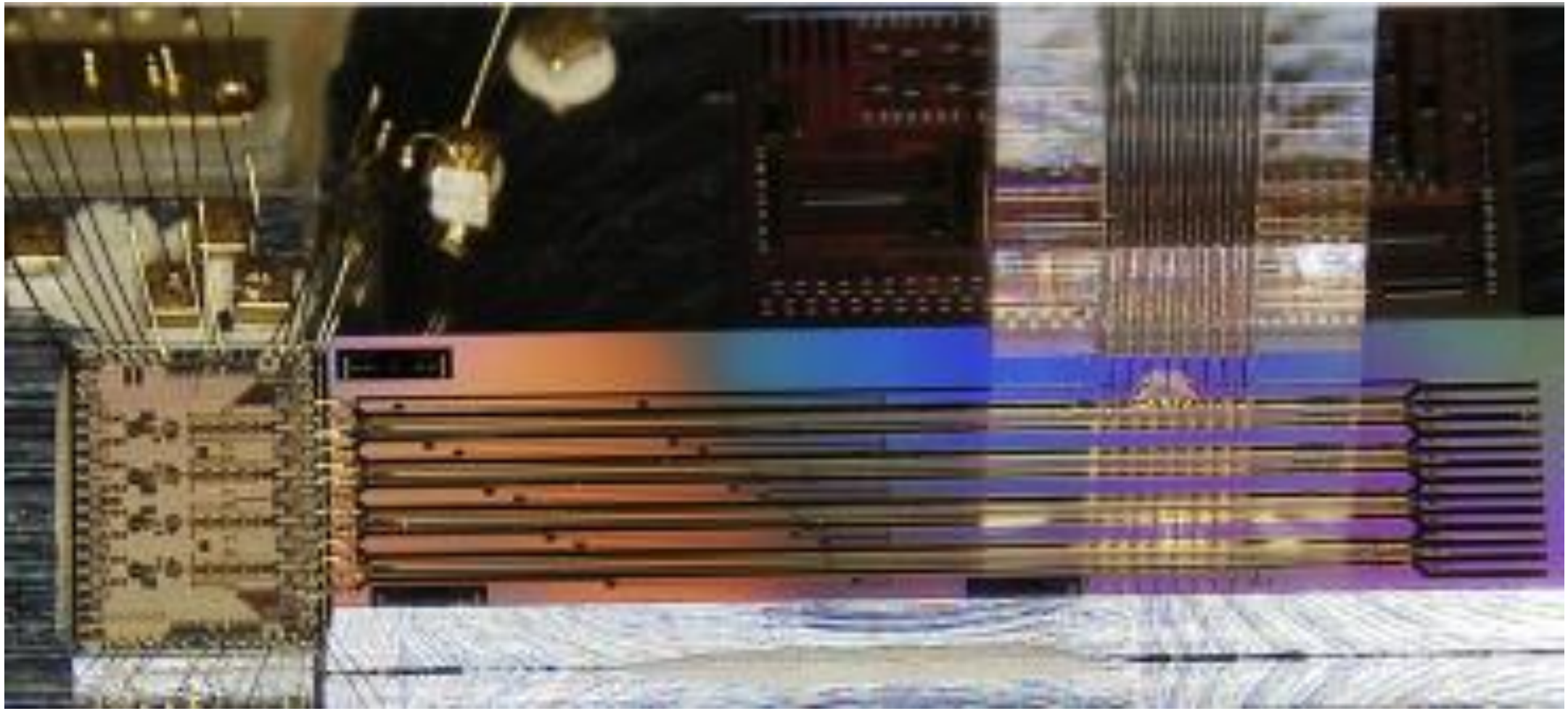
217 Hybrid structures

Consistently low insertion loss and propagation loss in the hybrid sections

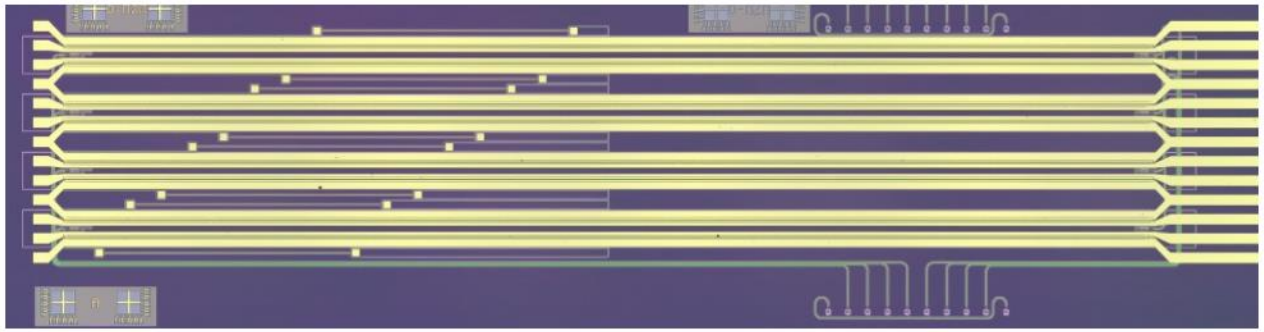


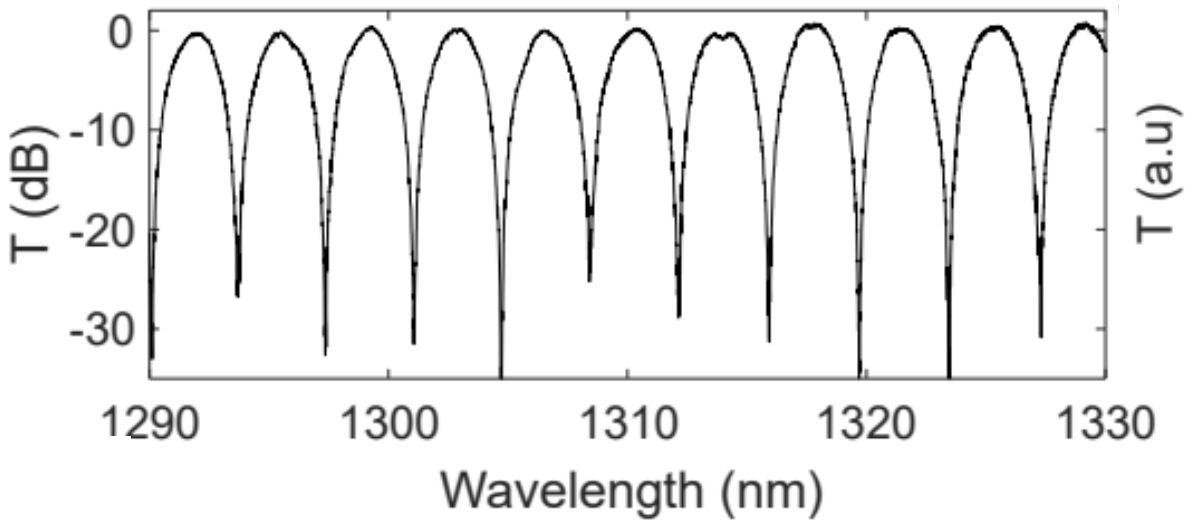


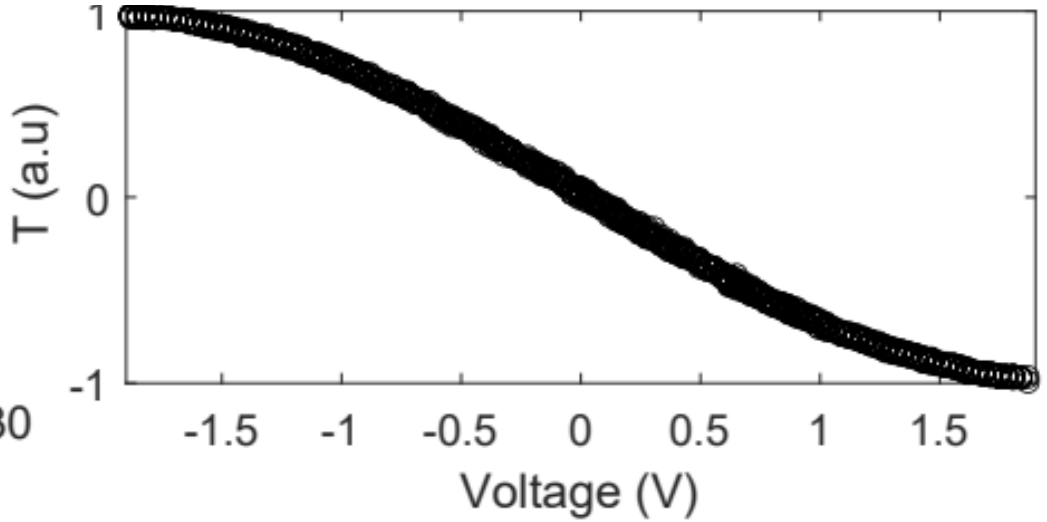
WP3: High-Speed Modulator



Characteristics of the hybrid LN-on-Si modulator







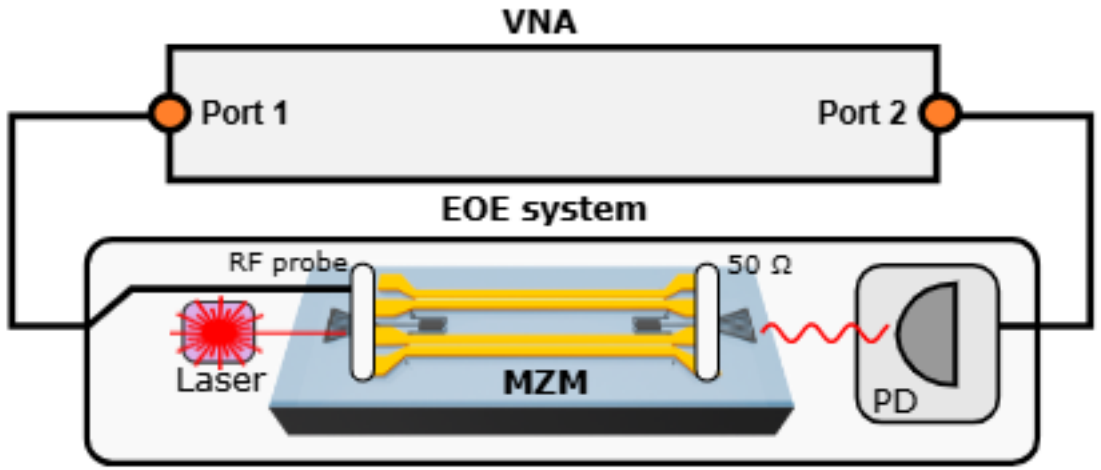
Transition loss from Si to LN/SiN modulator: 0.3 dB

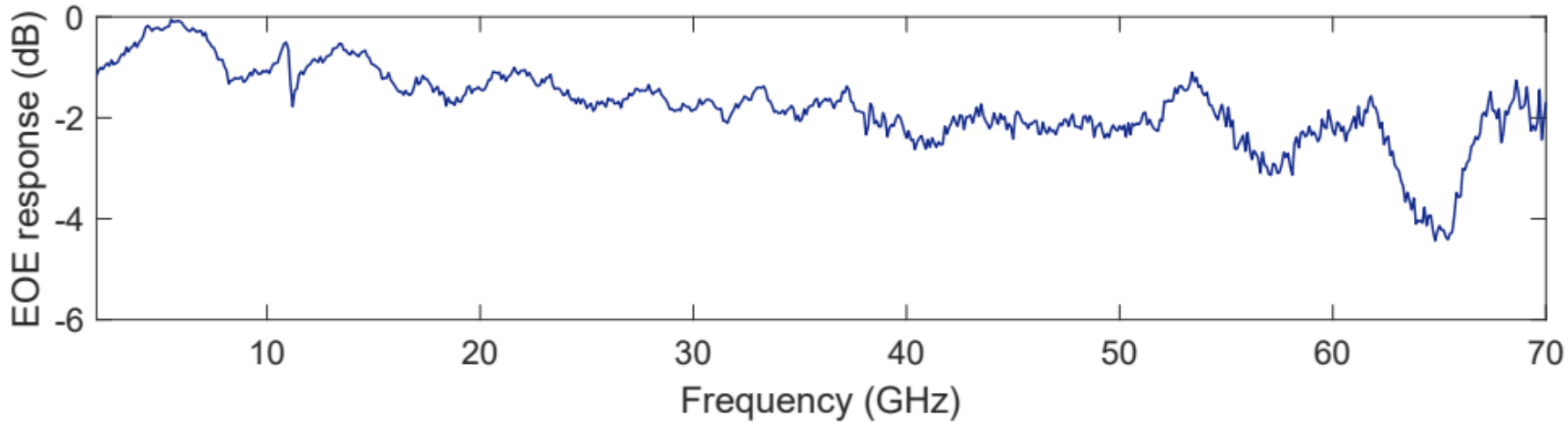
Loss of 7 mm long phase section: 0.5 dB

Total insertion loss of single phase modulator 1.1 dB

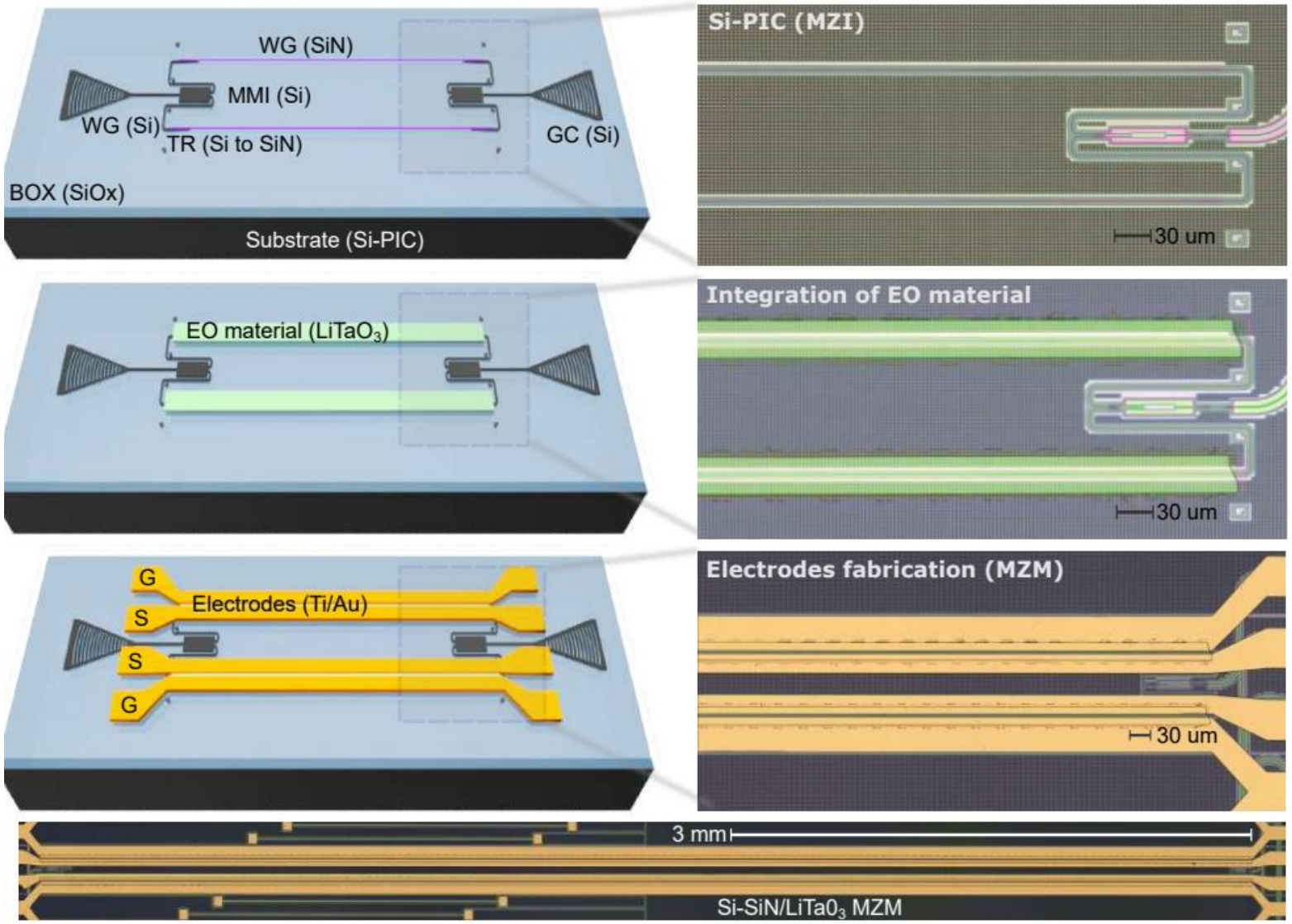
VpiL = 2.5 Vcm

The Hybrid modulator allows for high speed operation

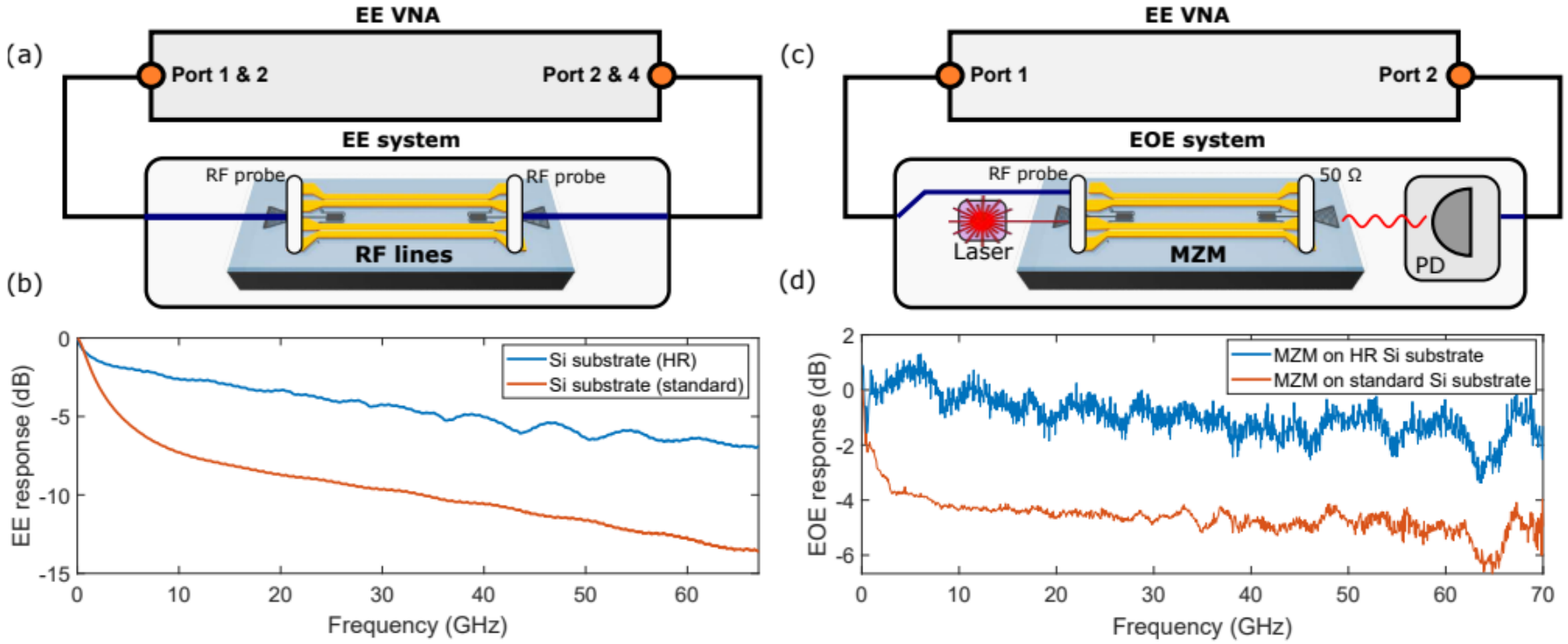




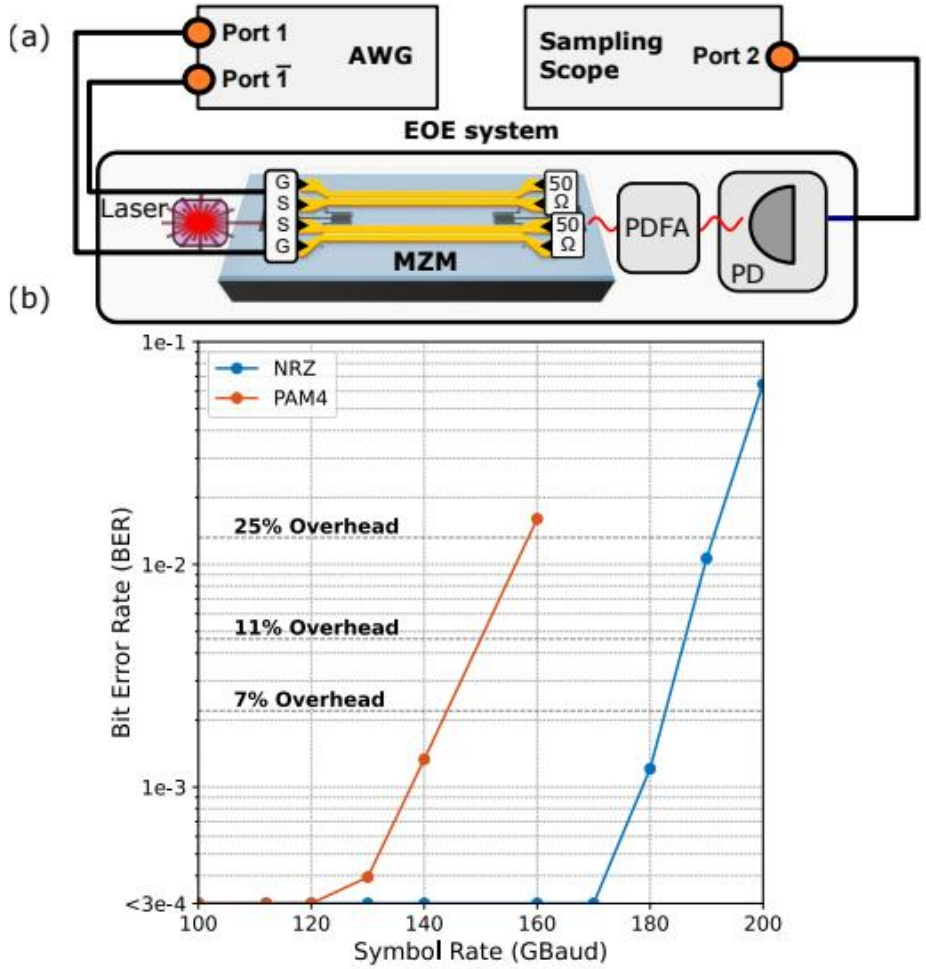
Similar fabrication process as LN to transfer LT

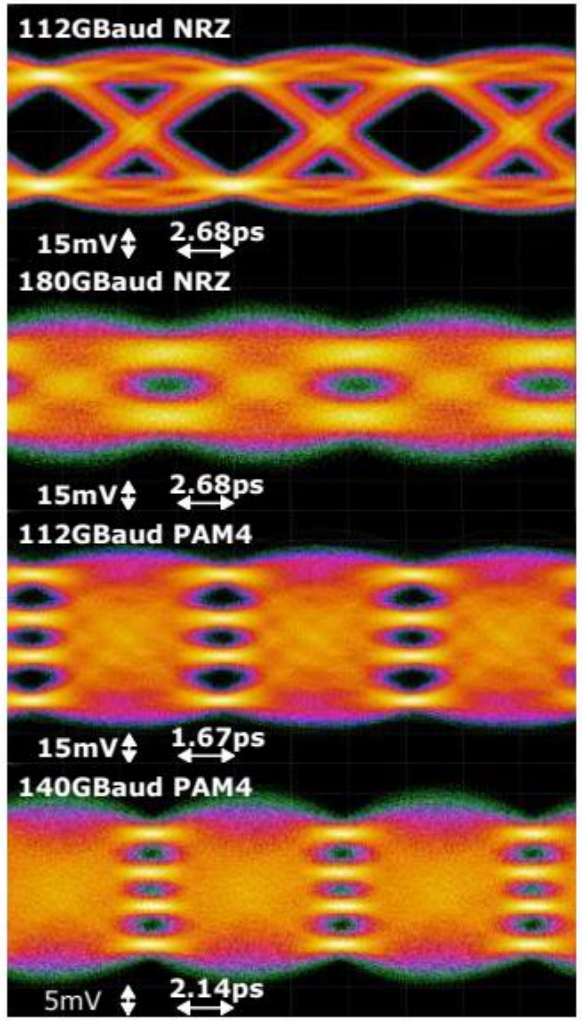


Electric and Opto-electric measurements of the devices



Generation of Eye-Diagrams





WP4: Passive performance

- PDK components perform according to specs

Transfer printed devices passive performance

- Alignment 3sigma better than 500 nm
- Insertion loss better than 2dB
- Extinction ratio higher than 15 dB

WP5: Exploitation and dissemination

- 300 mm European fab
- X-fab added LN to their progress track through Photonixfab
- Several American customers looking for demo wafers for Data- and Telecom

WP5: Exploitation and dissemination

- Post-Deadline Presentation at CLEO 2025

Lithium tantalate high-speed modulators on a silicon photonics platform

Tom Vanackere,[1, 2, *, †] Margot Niels,[1, 2, *, †] Ewoud Vissers,[1, 2] Tingting Zhai,[1, 2] Patrick Nenezic,[1, 2] Jakob Declercq,[2, 3] Cédric Bruynsteen,[2, 3] Shengpu Niu,[2, 3] Arno Moerman,[2, 3] Olivier Caytan,[2, 3] Nishant Singh,[2, 3] Sam Lemey,[2, 3] Xin Yin,[2, 3] Sofie Janssen,[2] Peter Verheyen,[2] Neha Singh,[2] Dieter Bode,[2] Martin Davi,[2] Filippo Ferraro,[2] Philippe Absil,[2] Sadhishkumar Balakrishnan,[2] Joris Van Campenhout,[2] Günther Roelkens,[1, 2] Maximilien Billet[1, 2, *] and Bart Kuyken,[1, 2, *]

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[†] *These authors contributed equally to this work.*

[*] *Tom.Vanackere@UGent.be*

WP5: Exploitation and dissemination

- Post-Deadline Presentation at CLEO 2025
- Paper Accepted at Nature Photonics

nature photonics

A high-speed heterogeneous lithium tantalate silicon photonics platform

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[†] *These authors contributed equally to this work.*
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WP5: Exploitation and dissemination

- Post-Deadline Presentation at CLEO 2025
- Paper Accepted at Nature Photonics
- Upgraded Presentation at ECOC 2025

Tu.01.03.4

320 Gb/s Unamplified Transmission using 100 GHz Ge PD and TFLN MZM on a Foundry-Compatible SiPh Platform Co-Packaged with Traveling-Wave Drivers and TIAs

Jakob Declercq[1], Shengpu Niu[1], Margot Niels[2], Amir Shahin[2,3], Joris Van Kerrebrouck[1], Maximilien Billet[2], Mathias Berciano[3,†], Joris Lambrecht[1,†], Bart Moeneclaey[1], Tom Vanackere[2], Ewoud Vissers[2], Conor Coughlan[3], Gunther Roelkens[2], Arno Moerman[1], Olivier Caytan[1], Sam Lemey[1], Maumita Chakrabarti[3], Hakim Kobbi[3], Minkyu Kim[3], Didit Yudistra[3], Roger Loo[3,4], Swetanshu Bipul[3], Filippo Ferraro[3], Yoojin Ban[3], Peter De Heyn[3], Guy Torfs[1], Johan Bauwelinck[1], Dimitrios Velenis[3], Peter Ossieur[1], Philippe Absil[3], Bart Kuyken[2], Joris Van Campenhout[3], Nishant Singh[1], Cedric Bruynsteen[1], Xin Yin[1]

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