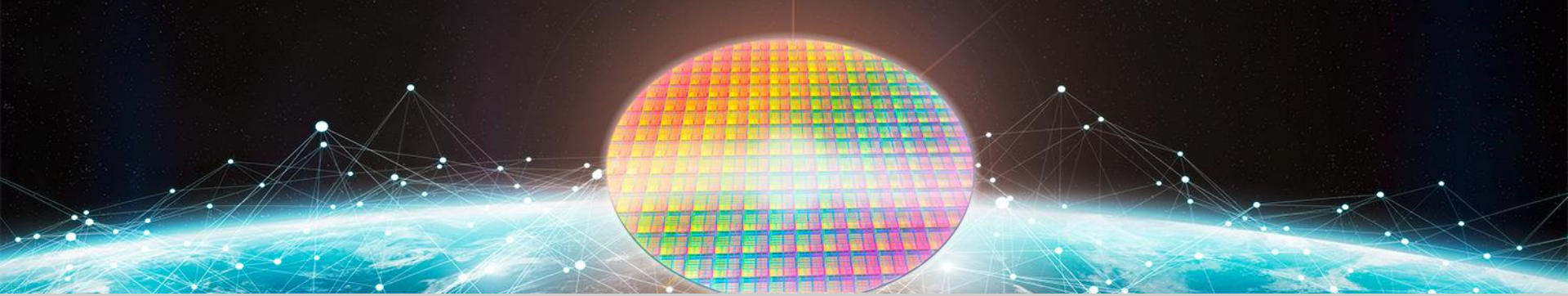

Functional Materials in Silicon-Photonics: More than Moore

Patrick Steglich

March 2021

IHP – Leibniz-Institut für innovative Mikroelektronik

Contributors

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Friedhelm Heinrich

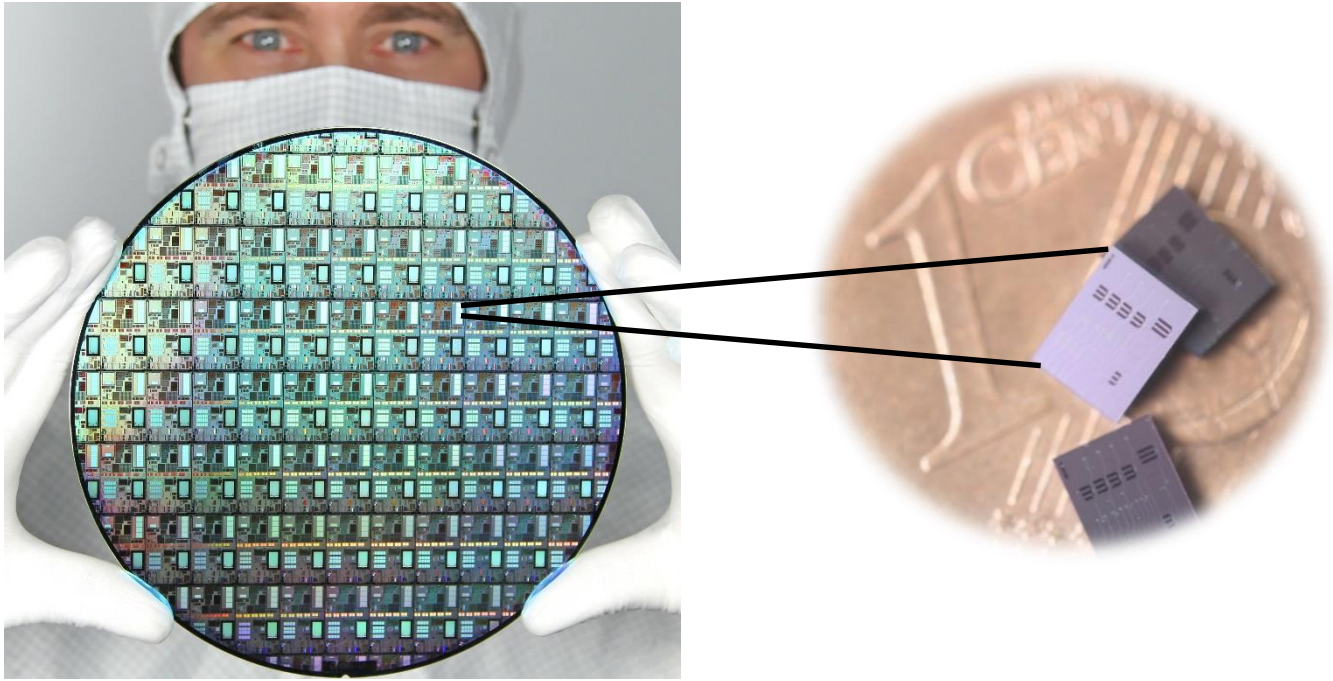
… AG von Prof. S. Schrader

Martin Paul

Michael G. Weller

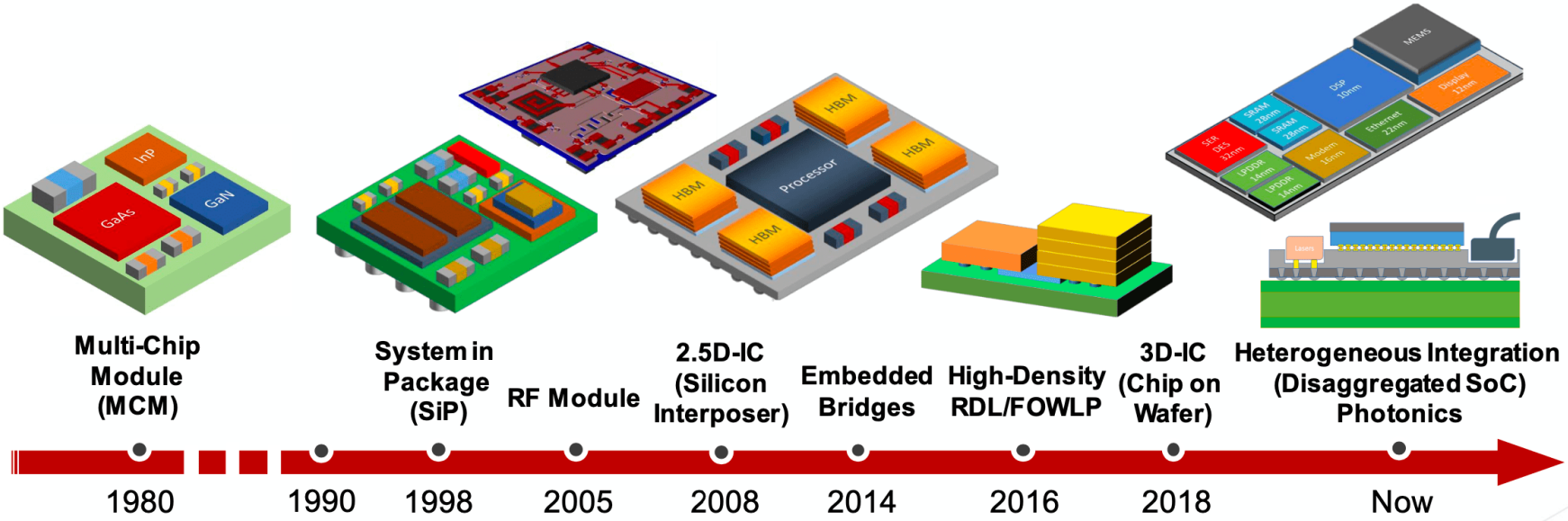
Introduction

Our technology is based on chip-integrated photonic devices in a CMOS-technology.



Introduction

More than Moore = Functionalities!



Source: https://semiengineering.com/more-than-moore-reality-check/

Agenda

Functional materials for…

1) Communication	2) Sensing

Heterogeneous integration by…

3) µ-Transfer-Printing

Agenda

Functional materials for…

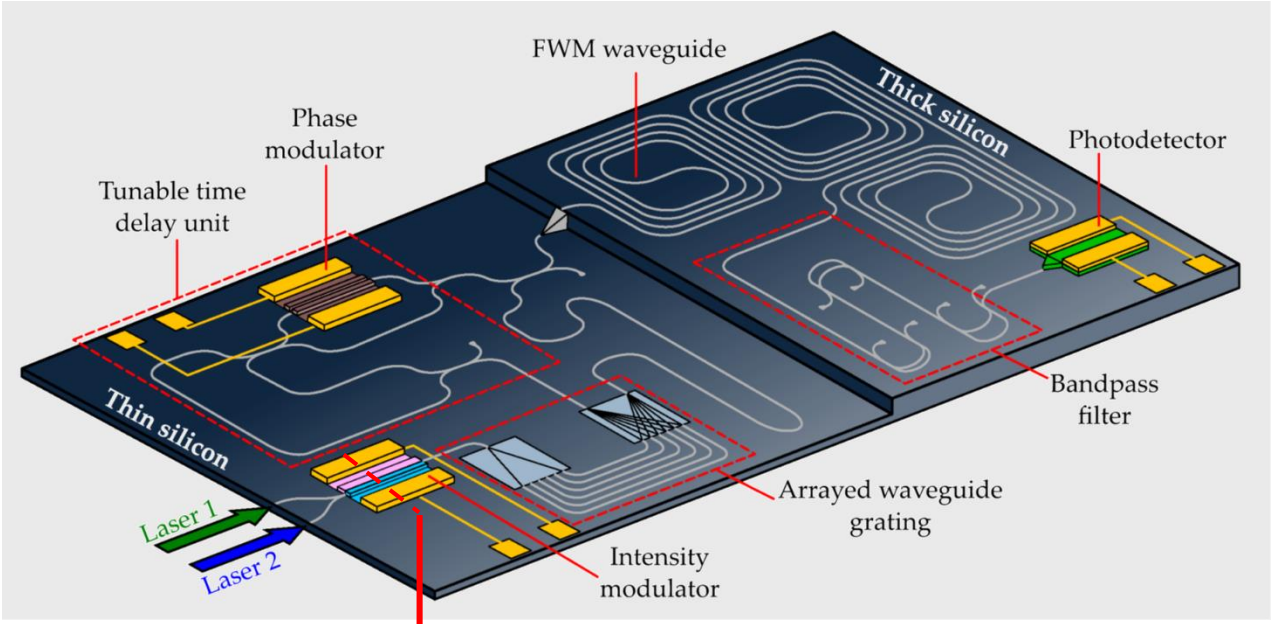
1) Communication

2) Sensing

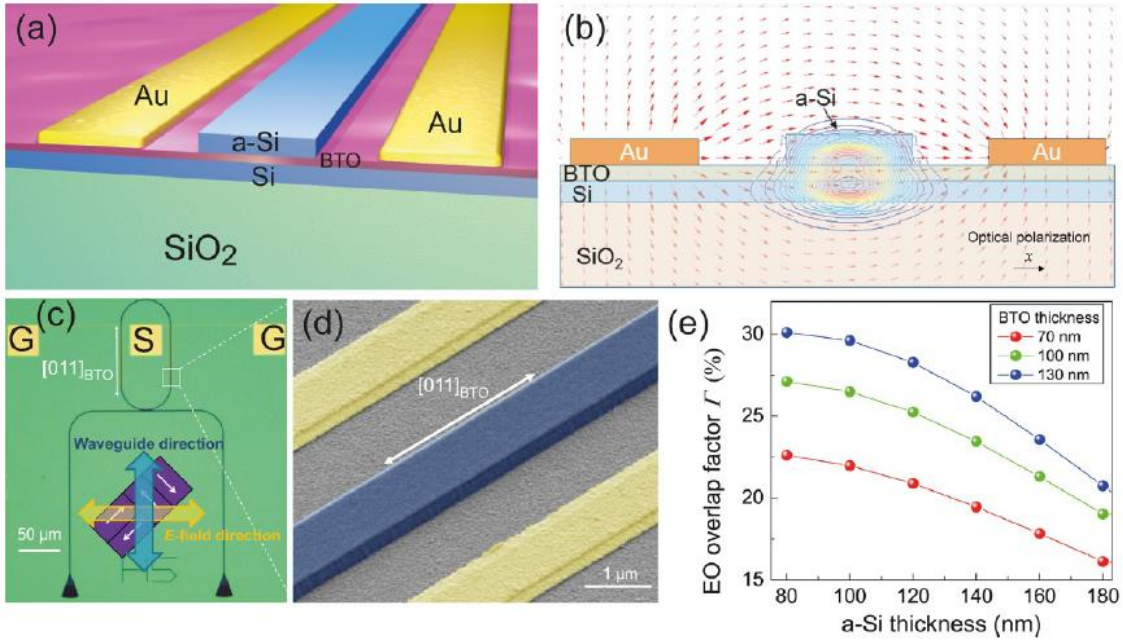
Heterogeneous integration by…

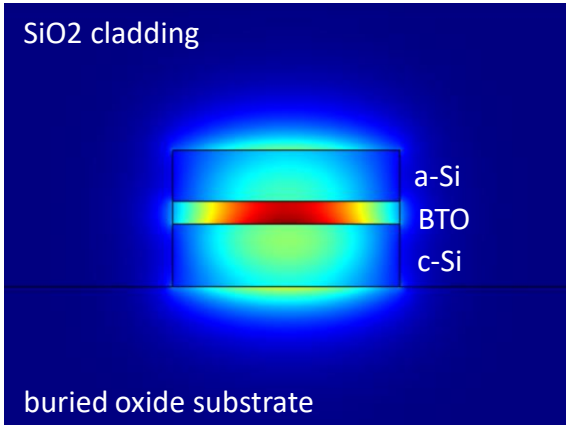
3) µ-Transfer-Printing

1) Communication



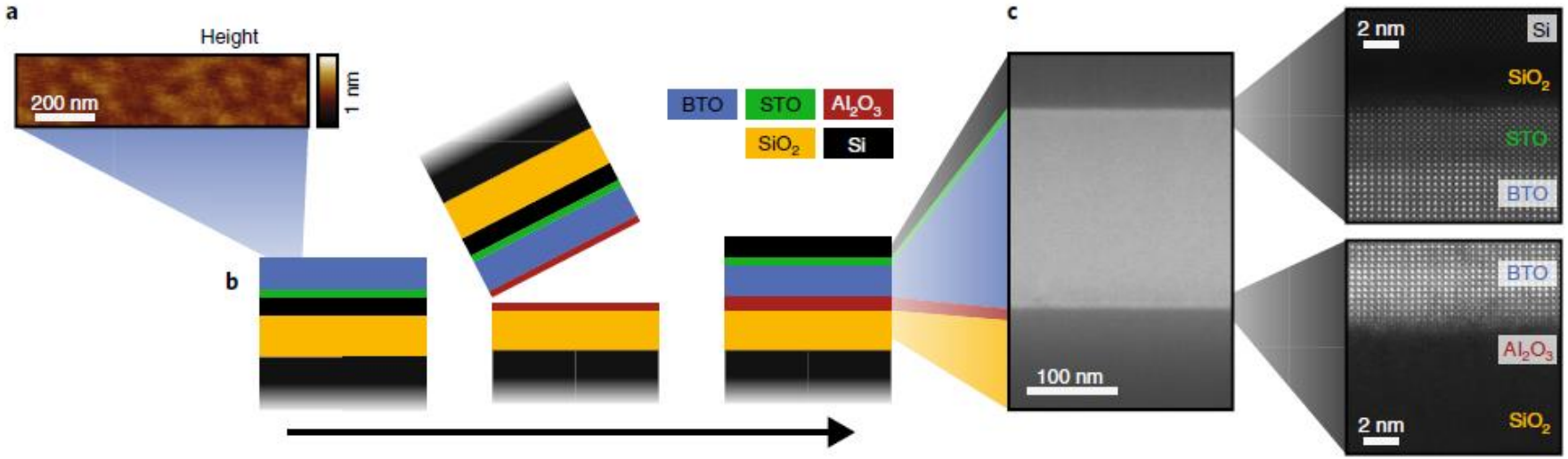
1) Communication





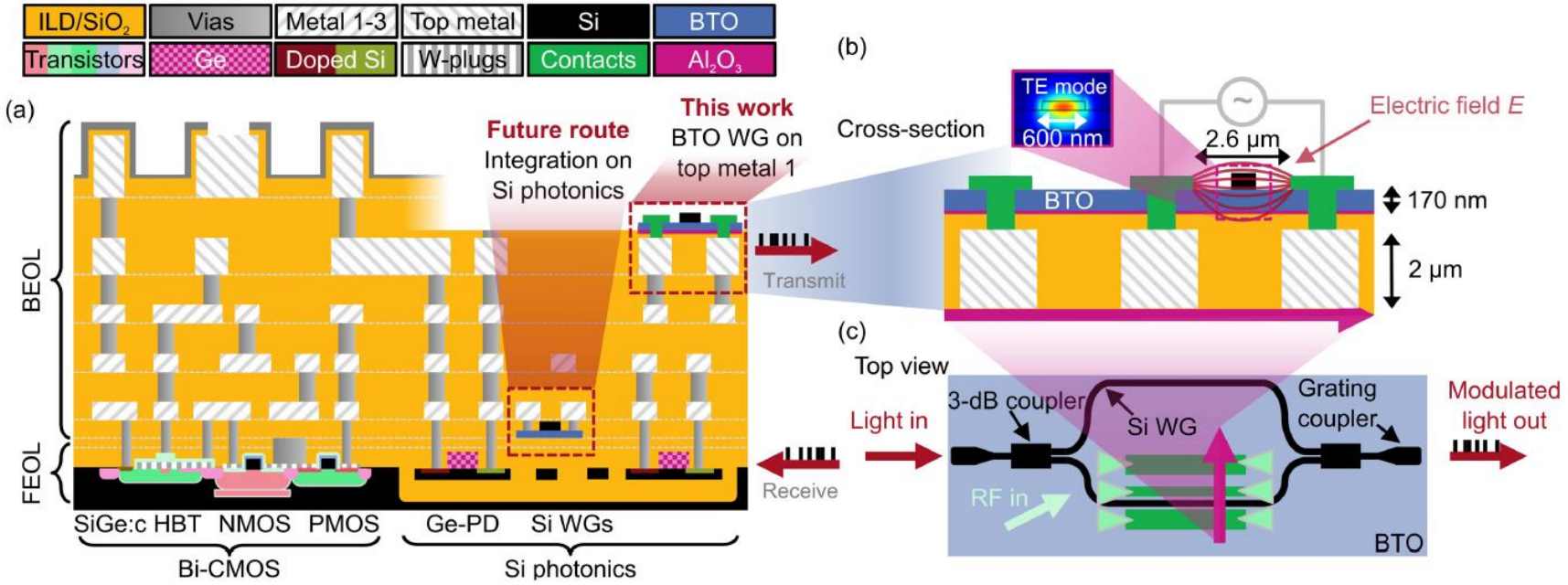
Xiong, Chi, et al. "Active silicon integrated nanophotonics: ferroelectric BaTiO3 devices." *Nano letters* 14.3 (2014)

1) Communication



Abel, Stefan, et al. "Large Pockels effect in micro-and nanostructured barium titanate integrated on silicon." *Nature materials* 18.1 (2019): 42-47.

1) Communication



F. Eltes *et al*., "A BaTiO3-Based Electro-Optic Pockels Modulator Monolithically Integrated on an Advanced Silicon Photonics Platform," *Journal of Lightwave Technology*, vol. 37, no. 5, pp. 1456-1462, 2019

Functional Materials in Silicon-Photonics: More than Moore

Functional materials for…

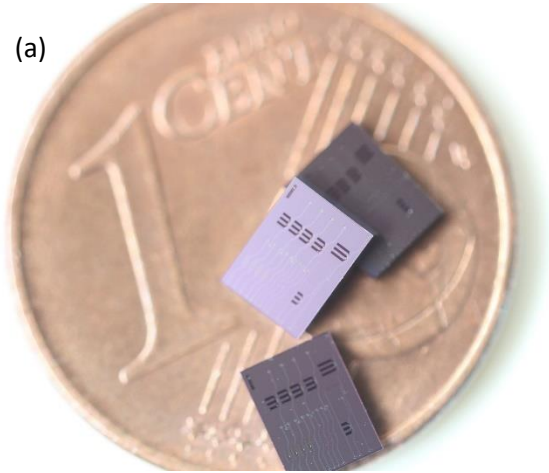
1) Communication

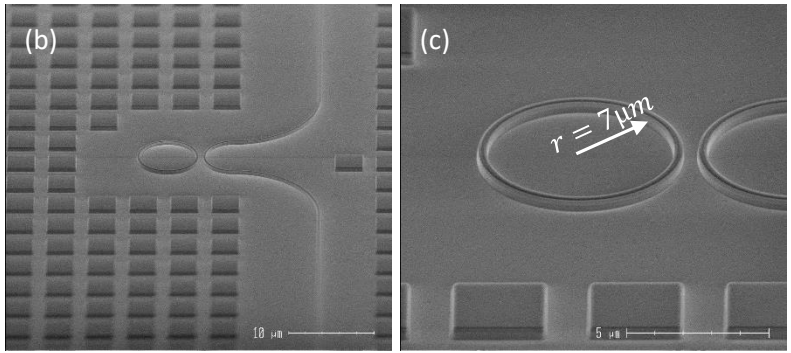
2) Sensing

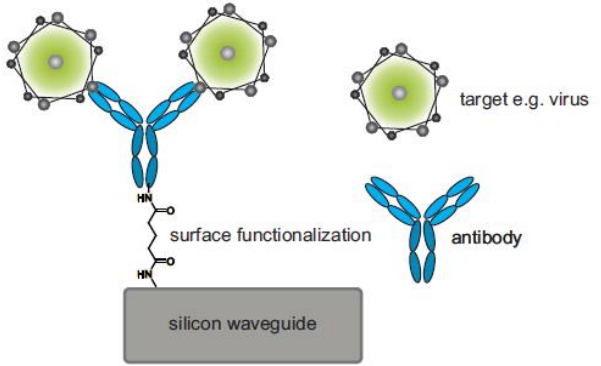
Heterogeneous integration by…

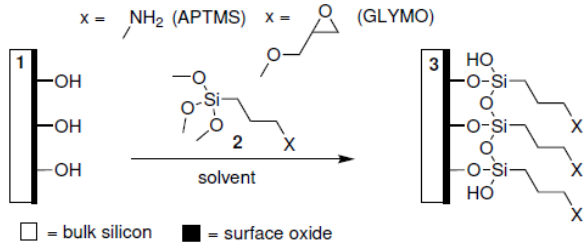
3) µ-Transfer-Printing

2) Sensing









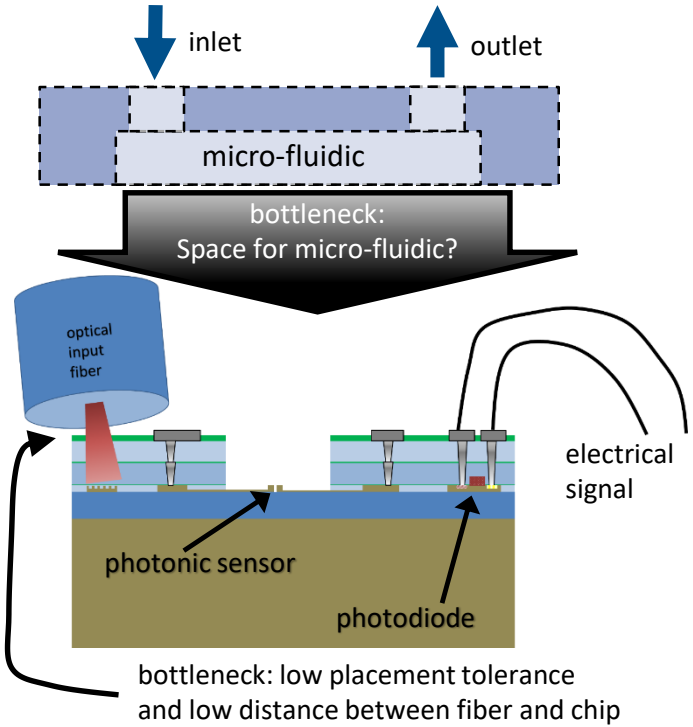
P. Steglich, D.G. Rabus, C. Sada, M. Paul, M.G. Weller, C. Mai, A. Mai, „Silicon Photonic Micro-Ring Resonators for Chemical and Biological Sensing: A Tutorial", *IEEE Sensors Journal* (to be submitted)

2) Sensing

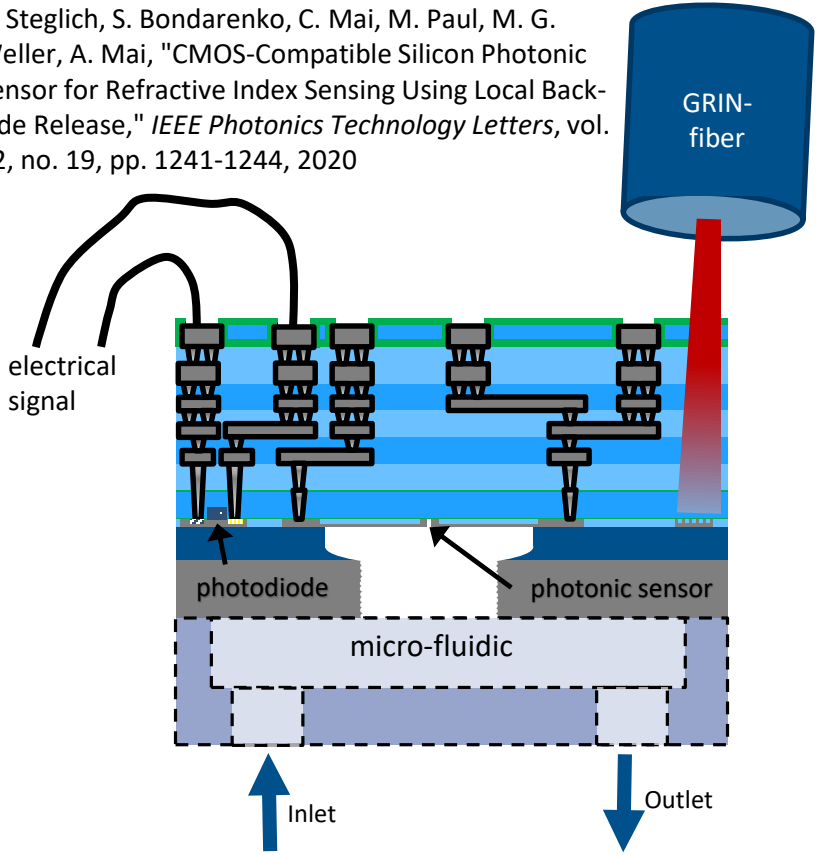
Application	Analyte/Biomarker	Receptor/Target	Detection Limit
Acute inflammation	C-reactive protein (CRP)	Anti-CRP	6.5 pM
Acute inflammation	Interleukin 2,4,5	Anti-CRP	6–100 pM
HIV	Human immunoglobulin (Hu-IgG)	Anti-Hu-lgG	1 ng
Hepatitis	Human serum albumin	Anti-Albumin	3.4 pg
Meningitis	tmRNA	DNA	0.524 nM
Prostate cancer	Prostate specific antigen (PSA)	Anti-PSA	0.4 nM
Liver cancer	α-fetoprotein (AFP)	Anti-AFP	100 pM
Bowel cancer	Carcinoembrionic antigen (CEA)	Anti-CEA	10 pM
Bladder cancer	Tumor necrosis factor (TNF)	Antibody	100 pM
Model system	Green fluorescent protein (GFP)	Antibody	0.1 mg/mL
Model system	Streptavidin	Biotin	60–150 fM
Food monitoring	Bean pod mottle virus	Antibody	1.43 pM

P. Steglich, M. Hülsemann, B. Dietzel, A. Mai, "Optical Biosensors Based on Silicon-On-Insulator Ring Resonators: A Review", *Molecules*, 24(3):519, 2019

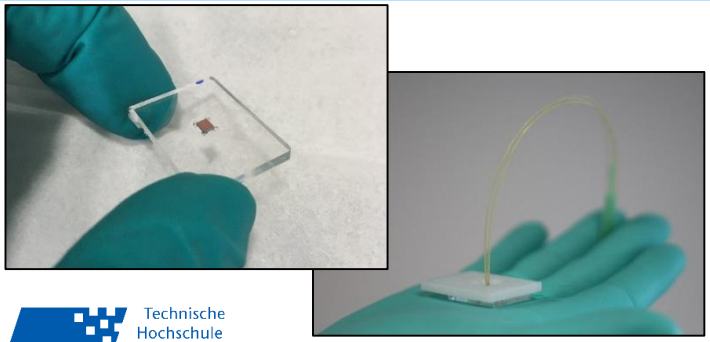
2) Sensing



P. Steglich, S. Bondarenko, C. Mai, M. Paul, M. G. Weller, A. Mai, "CMOS-Compatible Silicon Photonic Sensor for Refractive Index Sensing Using Local Back-Side Release," *IEEE Photonics Technology Letters*, vol. 32, no. 19, pp. 1241-1244, 2020

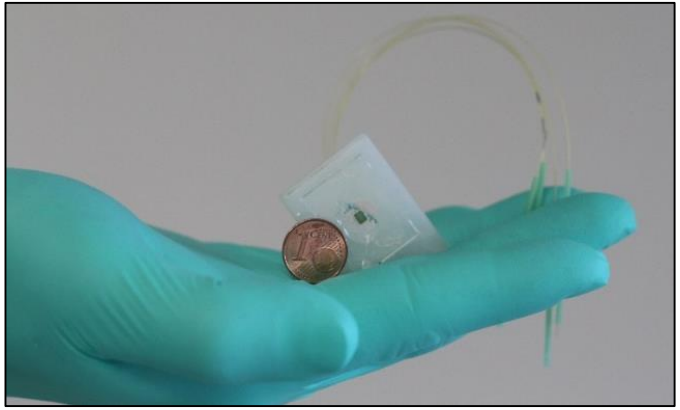


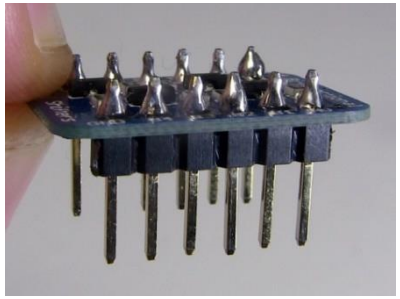
2) Sensing

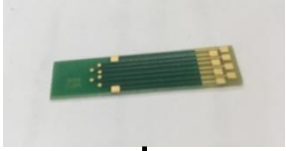


Technische Hochschule Wildau
Technical University of Applied Sciences

Thanks to Andrea Böhme







Agenda

Functional materials for…

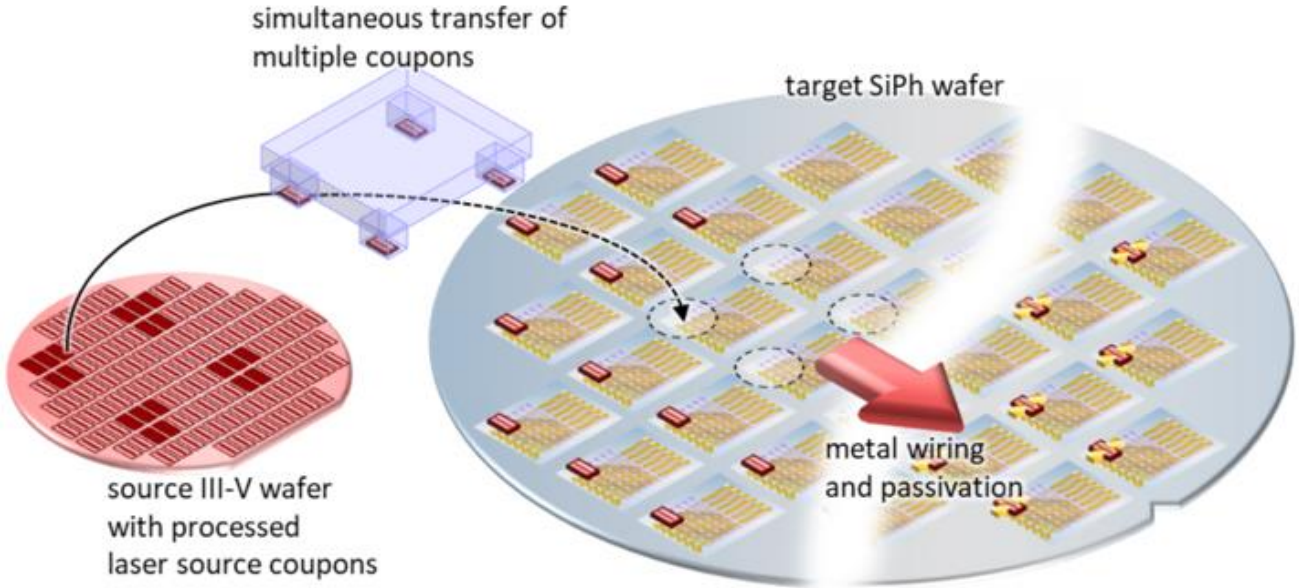
1) Communication

2) Sensing

Heterogeneous integration by…

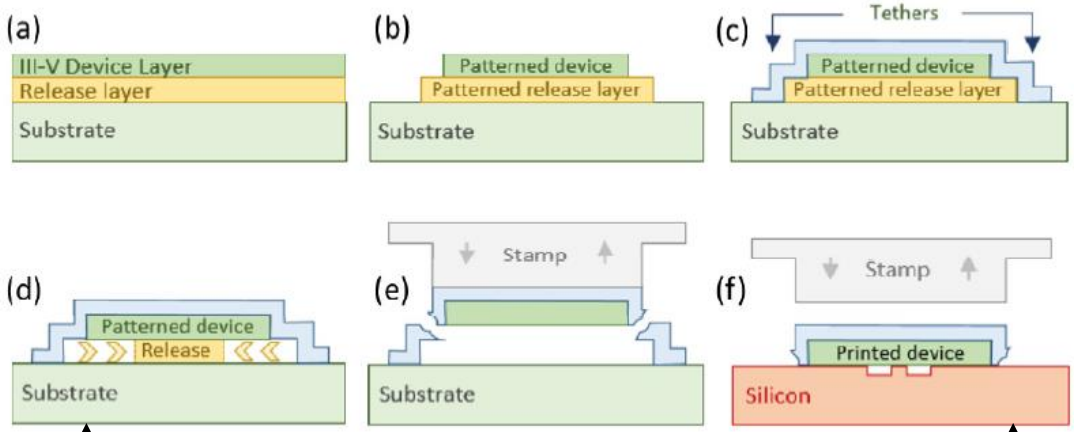
3) µ-Transfer-Printing

3) µ-Transfer-Printing

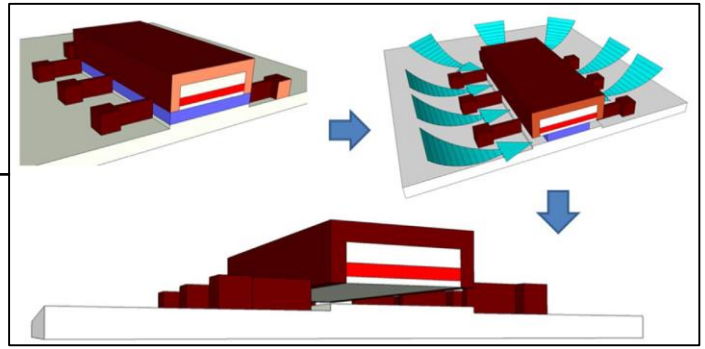


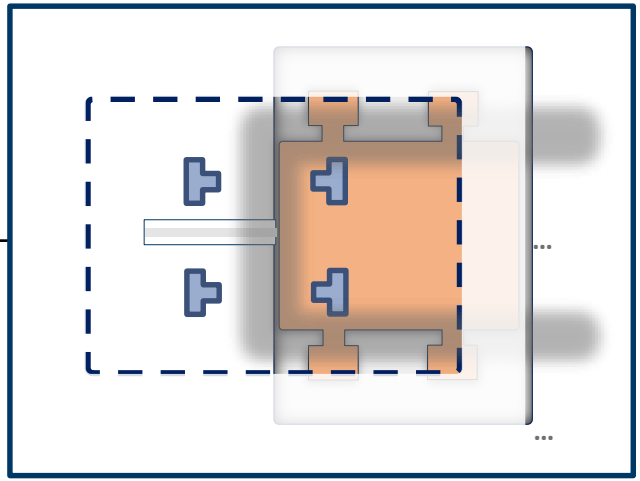
- Transfer of thin membranes (d = 0.5 - 15 µm)
- Transfer of small chiplets (5 µm x 5 µm)
- High alignment accuracy
  (less than ± 1.5 µm → typically 0.5 µm)

3) µ-Transfer-Printing

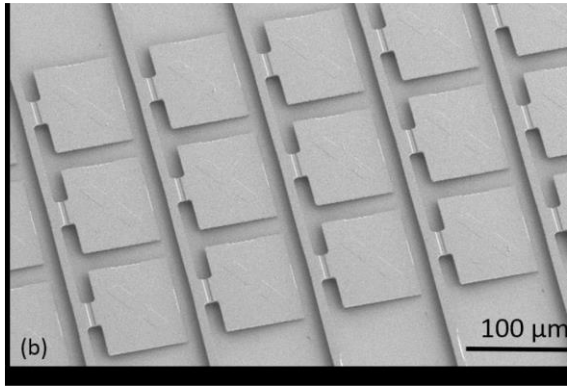


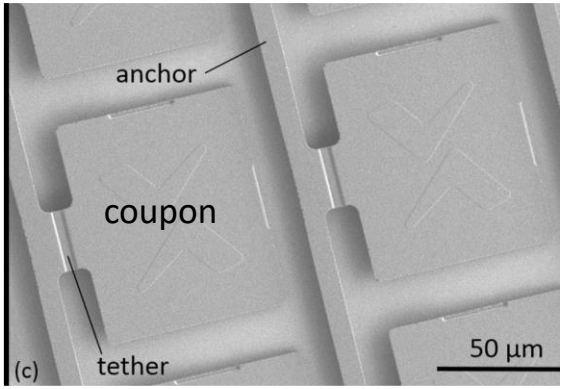
underetch

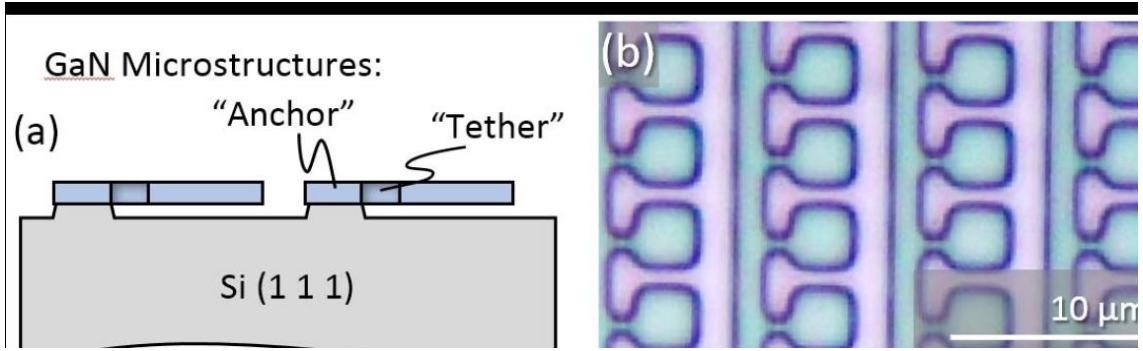




3) µ-Transfer-Printing

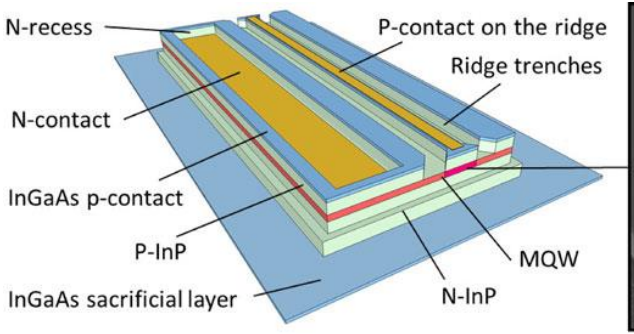


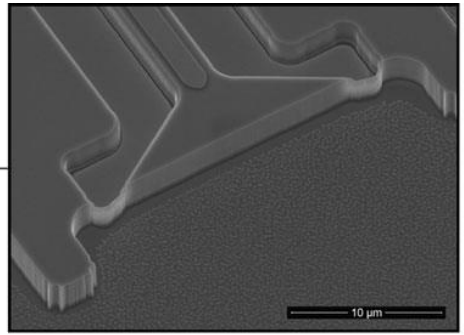


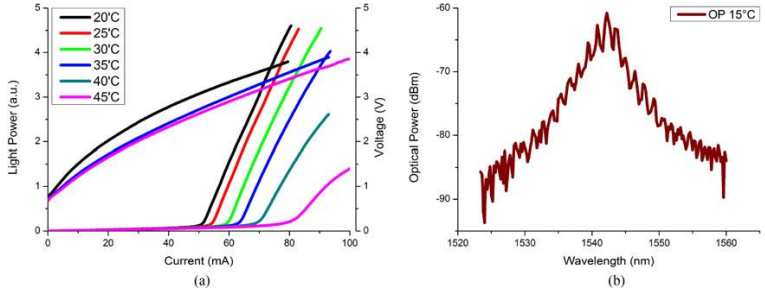


Source: X-Celeprint Inc.

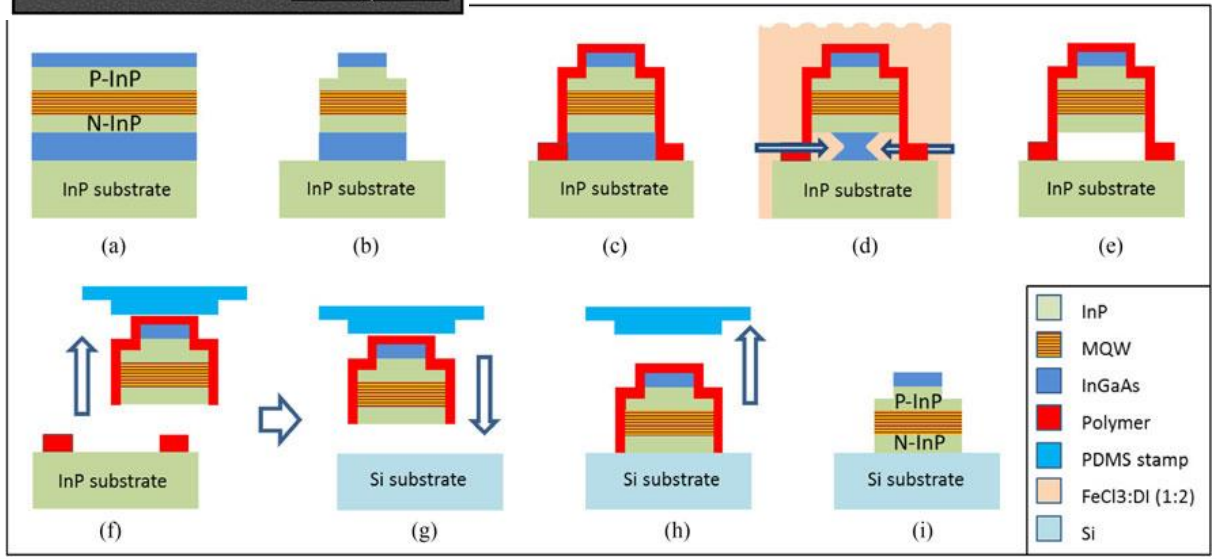
3) µ-Transfer-Printing







- 500µm × 60µm laser coupons are fabricated with a highly dense pitch on the native InP substrate



R. Loi *et al.*, "Transfer Printing of AlGaInAs/InP Etched Facet Lasers to Si Substrates," *IEEE Photonics Journal*, vol. 8, no. 6, pp. 1-10, Dec. **2016**.

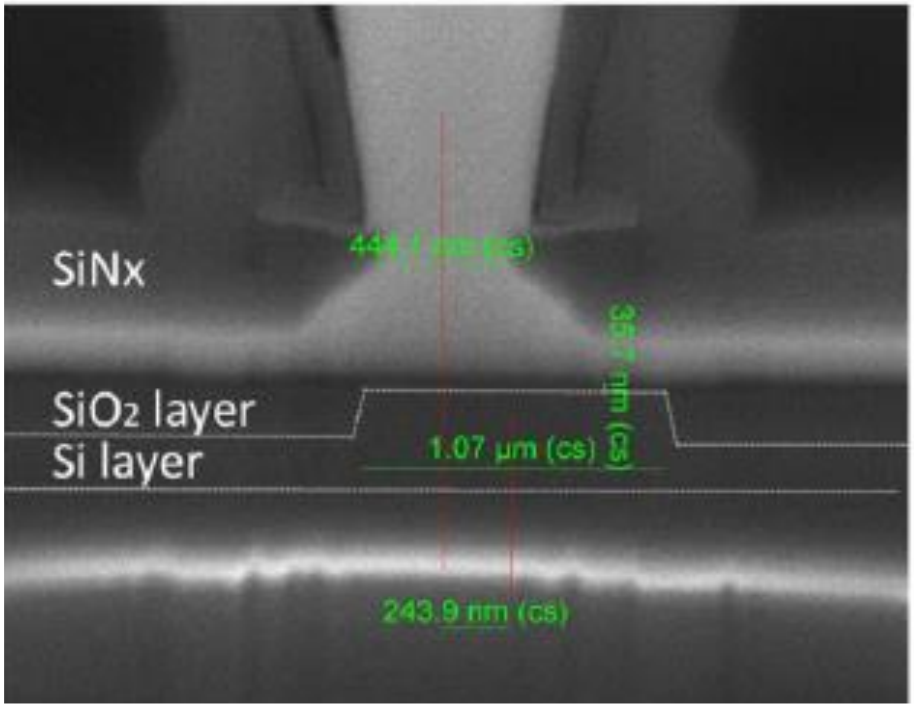
3) µ-Transfer-Printing

Layer	Layer type	Material	Thickness (nm)	Doping level (cm^{-3})	Dopant
26	Cap layer	InP	100	nid	
25	Contact P	InGaAs	100	$>1 \times 10^{19}$	Zn/C
24	Contact P	InGaAs	100	$\sim 1 \times 10^{19}$	Zn
23	Cladding P	InP	1000	$\sim 1 \times 10^{18}$	Zn
22	Cladding P	InP	500	$\sim 5 \times 10^{17}$	Zn
21	Transition	$(Al_{0.9}Ga_{0.1})_{.47}In_{.53}As$	40		
20	Confinement	$(Al_{0.7}Ga_{0.3})_{.47}In_{.53}As$	75		
9 × 6	Barrier	$(Al_{.45}Ga_{.65})_{.51}In_{.49}As$	10		
8 × 6	Quantum well	$(Al_{.25}Ga_{.75})_{.3}In_{0.7}As$	6		
7	Barrier	$(Al_{.45}Ga_{.65})_{.51}In_{.49}As$	10		
6	Confinement	$(Al_{0.7}Ga_{0.3})_{.47}In_{.53}As$	75		
5	Transition	$(Al_{0.9}Ga_{0.1})_{.47}In_{.53}As$	40	1×10^{18}	Si
4	Cladding N	InP	200	2×10^{18}	Si
3	Etch stop	InP	60	nid	
2	Sacrificial layer	InGaAs	1000	nid	
1	Buffer	i-InP	150	nid	
0	Substrate	InP Sub		n-type	

- The overall thickness of the III-V layer stack that will be printed onto the target photonic circuit is around **2.3 µm**.
- 20 nm thick DVS-BCB bonding layer.
- 970 µm long and 40 µm wide coupons.

Jing Zhang, Bahawal Haq, James O'Callaghan, Angieska Gocalinska, Emanuele Pelucchi, António José Trindade, Brian Corbett, Geert Morthier, and Gunther Roelkens, "Transfer-printing-based integration of a III-V-on-silicon distributed feedback laser," Opt. Express 26, 8821-8830 (**2018**)

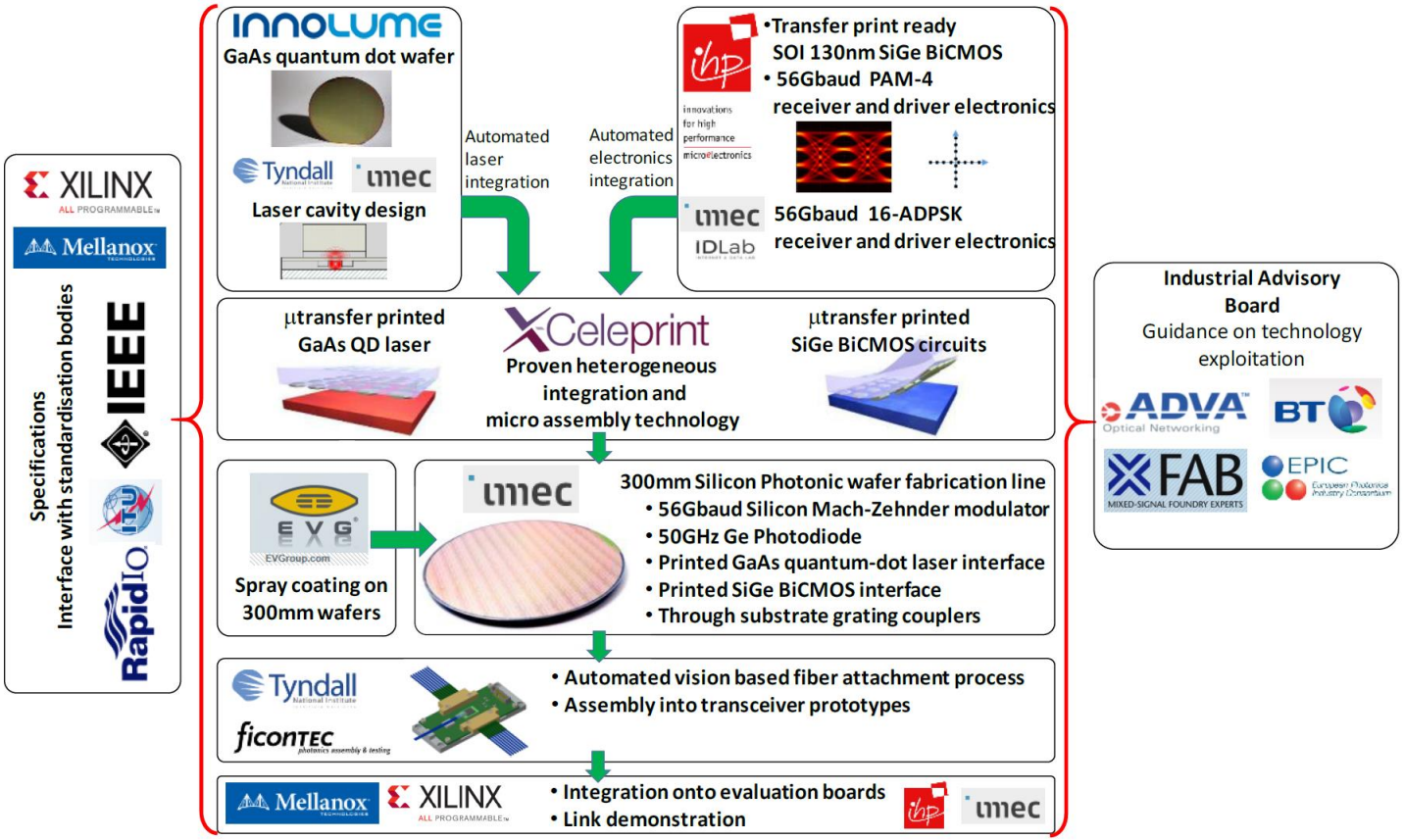
3) µ-Transfer-Printing



Jing Zhang et al., "Transfer-printing-based integration of a III-V-on-silicon distributed feedback laser," Opt. Express 26, 8821-8830 (**2018**)

3) µ-Transfer-Printing

EU-Project
CALADAN



Thank you for your attention!

Patrick Steglich

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