PHOTONICS RESEARCH GROUP

Manufacturable Solutions for Wafer-level Laser and SOA Integration on Silicon

Work in progress in Europe

Roel Baets

AIM PHOTONICS FALL 2018 ROADMAP MEETING,
Boston, Dec 28-30, 2018

GHENT UNIVERSITY

imec
embracing a better life

ePIXfab

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Proceedings OF THE IEEE

SPECIAL ISSUE

Silicon Photonics

Point of View: Thinking About the Robot Takeover

Scanning Our Past: Debugging the ENIAC

GHENT UNIVERSITY

ECIO 2019

24th April - 26th April 2019

Ghent University, Belgium

Paper submission now open (deadline: 18 January 2019)

21st EUROPEAN CONFERENCE ON INTEGRATED OPTICS

THE PAST 5-10 YEARS: STUNNING INDUSTRIAL DEVELOPMENT IN SILICON PHOTONICS, DRIVEN BY TELECOM/DATACOM

- active optical cables (eg PSM4: 4x28 Gb/s on parallel fibers)
- WDM transceivers (eg 4 WDM channels x 25 Gb/s on single fiber)
- coherent receiver (eg 100 Gb/s PM-QPSK)
- fiber-to-the-home bidirectional transceiver (eg 12 x 2.5 Gb/s)
- monolithic receiver (eg 16x20Gb/s)
- 40Gb/s, 50Gb/s and 100 Gb/s Ethernet (future: 400Gb/s)
- …

OUTLINE

- ➡ ePIXfab
- The options for light source integration
- Work in progress in Europe
  - Short term to market
  - Long term to market
  - Medium term to market

ePIXfab: European Alliance for Silicon Photonics

ePIXfab is an *open alliance* of European organizations that promotes silicon photonics science, technology and applications

Advocate

Latest advancements in the field

Represent

European silicon photonics community as a whole

Train

With respect to silicon photonics tech. & app.

Consult

To determine the feasibility for innovation

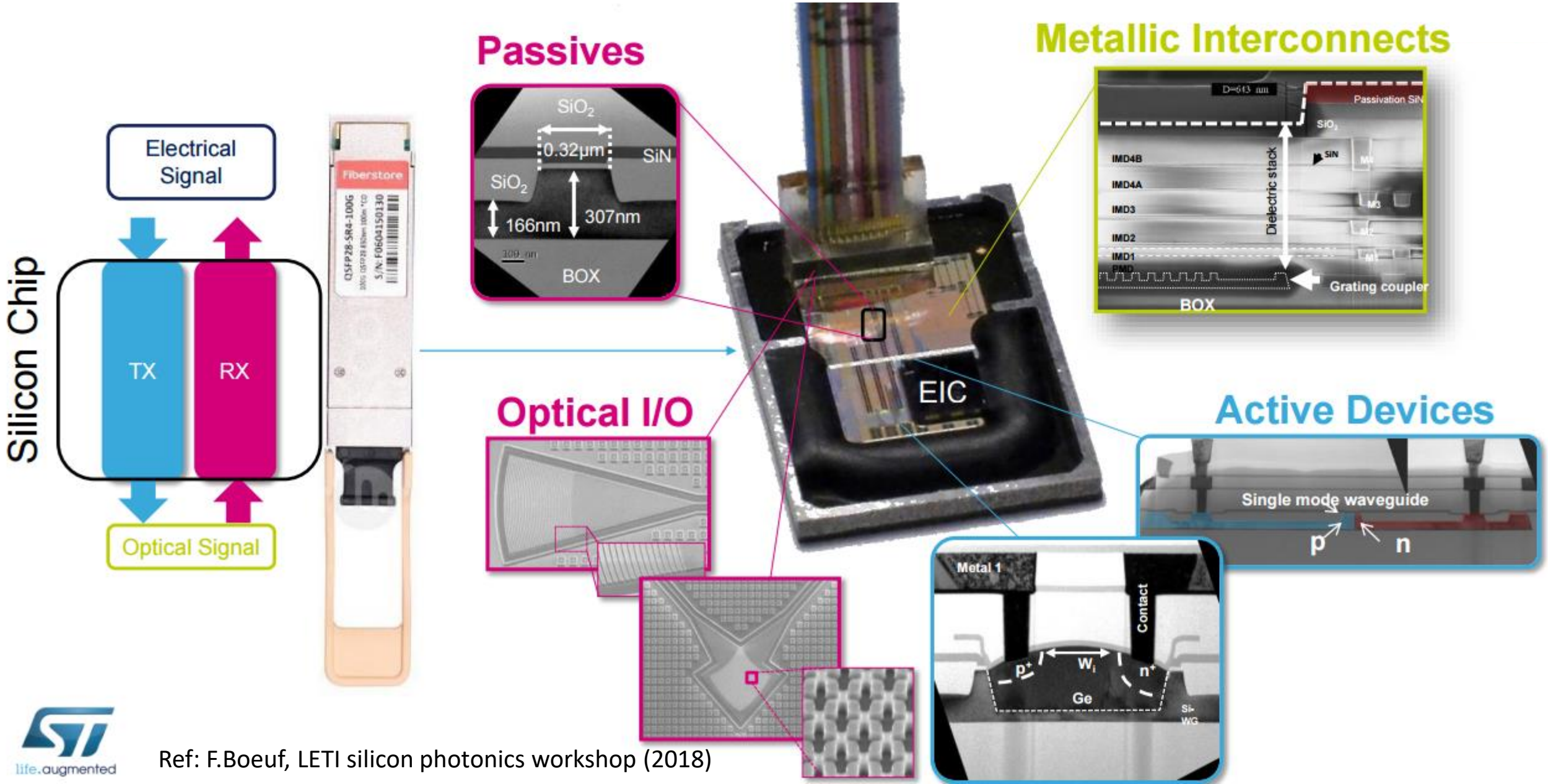
Roadmap

About the technological trends and evolution

ePIXfab Member Portfolio

Coordinator	200 YEARS GHENT UNIVERSITY
Fabs.	imec, ST, cea leti, ihp, VTT, LionIX, LIGENTEC, AMO, CNM
Design Tools	LUCEDA PHOTONICS, VPIphotonics, Photon Design, PhoenixSoftware, Nazca design
Design Houses	VLC PHOTONICS, BRIGHT Integrated PHOTONICS
Technology Brokers	EUROPRACTICE IC SERVICE, cmp
Epi	BROLIS SEMICONDUCTORS
Packaging	Tyndall National Institute
Industrial Consortium	EPIC European Photonics Industry Consortium
Academic Research	Valencia Nanophotonics Technology Center, IPH, RWTH AACHEN UNIVERSITY, Technische Universität Berlin, UNIVERSITY OF TRENTO - Italy Department of Physics, TNO, KIT Karlsruher Institut für Technologie, UNIVERSITY OF Southampton Optoelectronics Research Centre, AARHUS UNIVERSITY, cnit, UNIVERSITAT POLITÈCNICA DE VALÈNCIA, DTU Fotonik Department of Photonics Engineering, C2N

ST's 100G PSM4 - PIC25G Technology



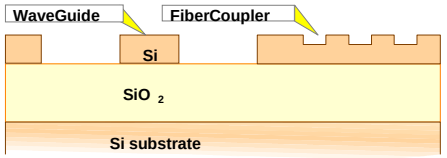
Ref: F.Boeuf, LETI silicon photonics workshop (2018)

Standardized Open Access SOI Technologies

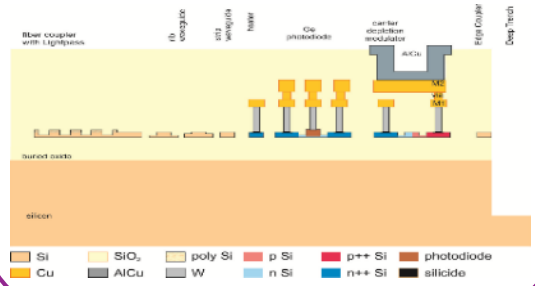
Accessible through MPW and dedicated engineering runs

imec

PSV



ISIPP50G



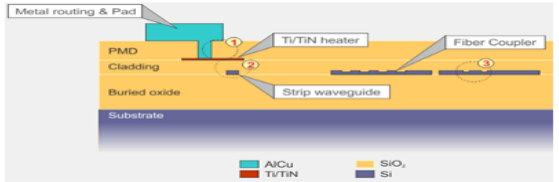
220 nm SOI platform

O/C band

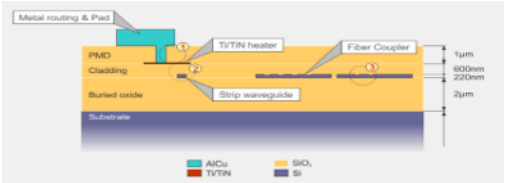
50G active devices

leti

Passive + heaters



Si310-PH



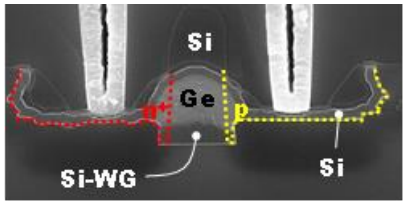
310 nm SOI platform

O/C band devices compatible

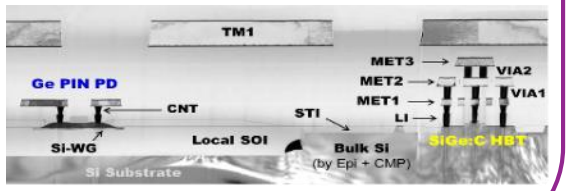
for III-V laser integration

ihp

IHP SG25_PIC



IHP SG25H4_EPIC



Photonic BiCMOS

Monolithic integration C-band

& BiCMOS (190GHz HBT)

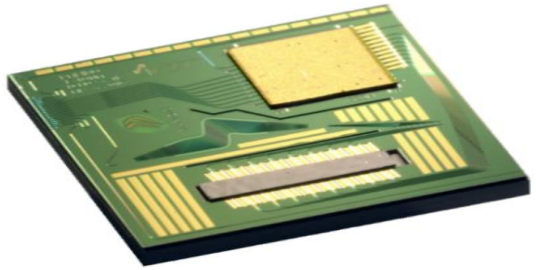
Standardized Open Access SOI Technologies

Accessible through MPW and dedicated engineering runs

Rapid prototyping services

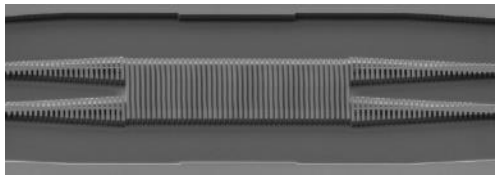
VTT

Passives
+ Implanted heaters
+ Implanted PIN
+ Flip-chip

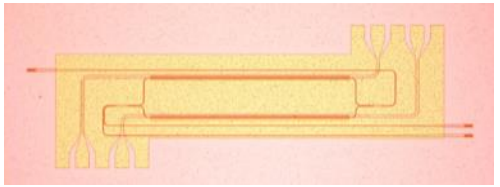


CORNERSTONE

Passive + heaters



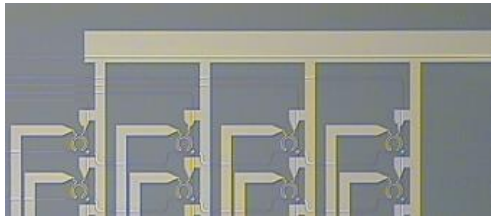
Actives

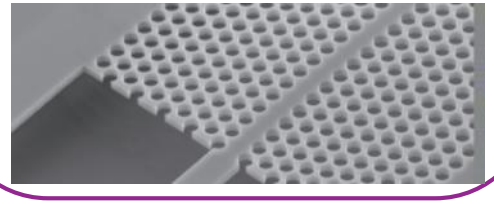


UNIVERSITY OF Southampton

AMO

Actives+Passives on 220nm
And 340 nm SOI using e-beam





Thick SOI

low loss + pol. independent

Flexible platform

custom implants, etch depth

Multiple SOI platforms

Flexible foundry platform

for customized wafer runs

Pilot lines and coordinating institutes

To strengthen **open access** mechanisms to photonic integration technology, driven by the needs of end users.

2016	2016	2017
MIRPHAB	**PIX4LIFE**	**PIXAPP**
*A manufacturing pilot line for **MID-IR Systems***	***SiN PIC pilot line** for life science applications in the visible range*	***PIC assembly & packaging** Pilot Line*
www.mirphab.eu	www.pix4life.eu	www.pixapp.eu

www.pixapp.eu/

Take-home message

- There is diversity in silicon photonics
  - Silicon layer thickness
  - Operation at different wavelengths
  - Integration with electronics, or not
  - Heterogeneous integration with III-V, or not

- This diversity brings substantial value to the end-user

- … as long as the “dilution” caused by diversity is not jeopardizing yield or cost

- **Where is the sweet spot between diversity and standardization?**

OUTLINE

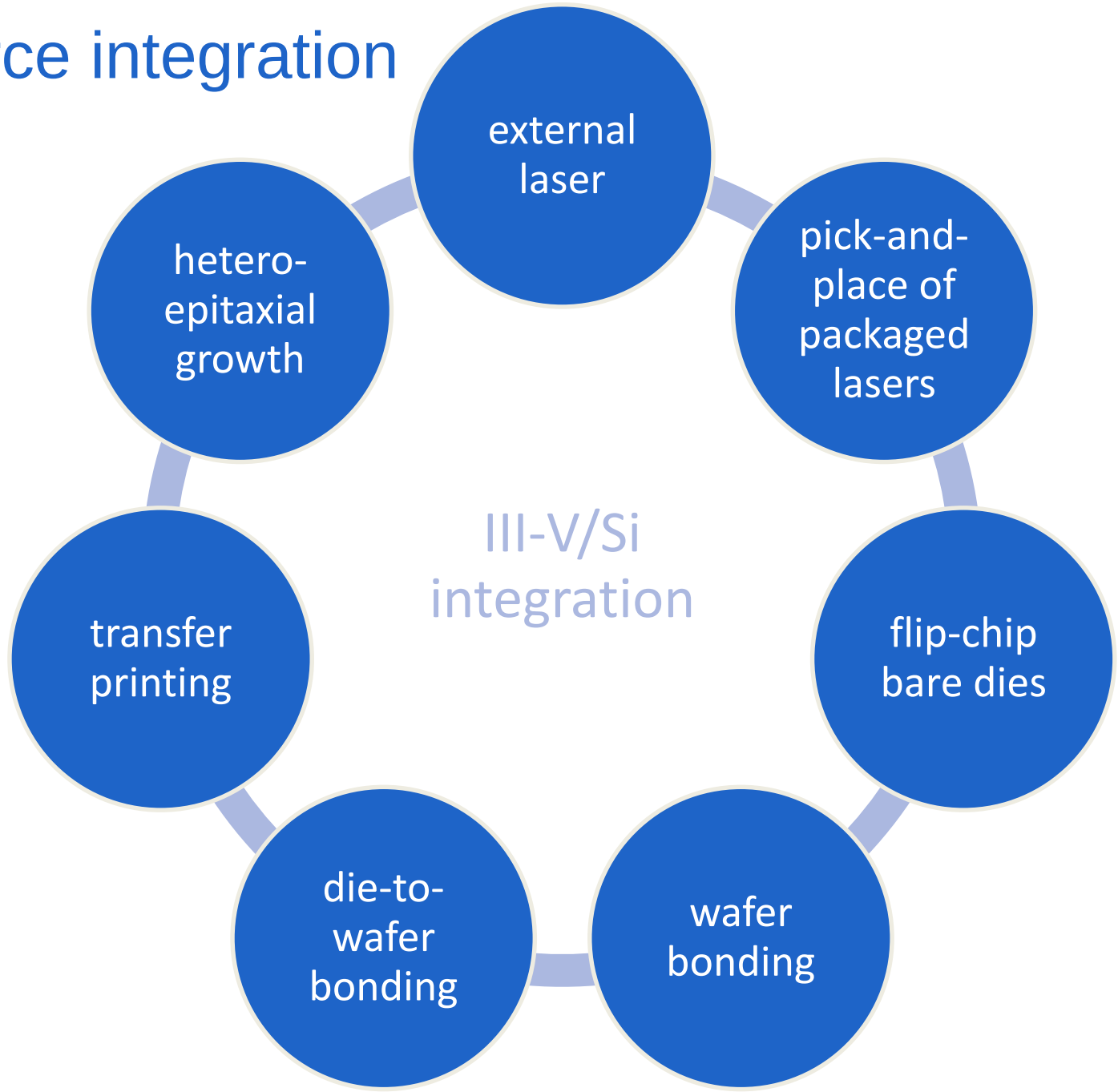
ePIXfab

➡ The options for light source integration

Work in progress in Europe

- Short term to market
- Long term to market
- Medium term to market

Options for light source integration

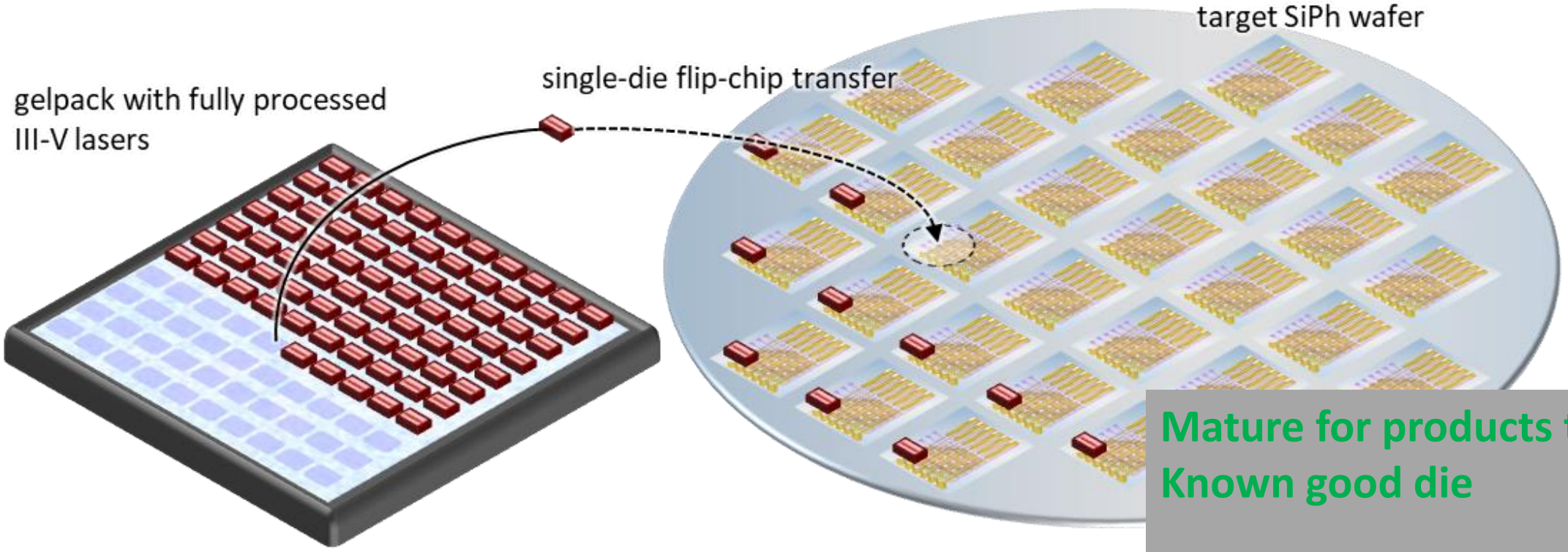


PIXAPP Photonic Packaging Pilot Line

GHENT UNIVERSITY imec

Approaches to hybrid III-V integration on SiPhotonics

Flip-chip integration of bare dies / pick-and-place of packaged devices

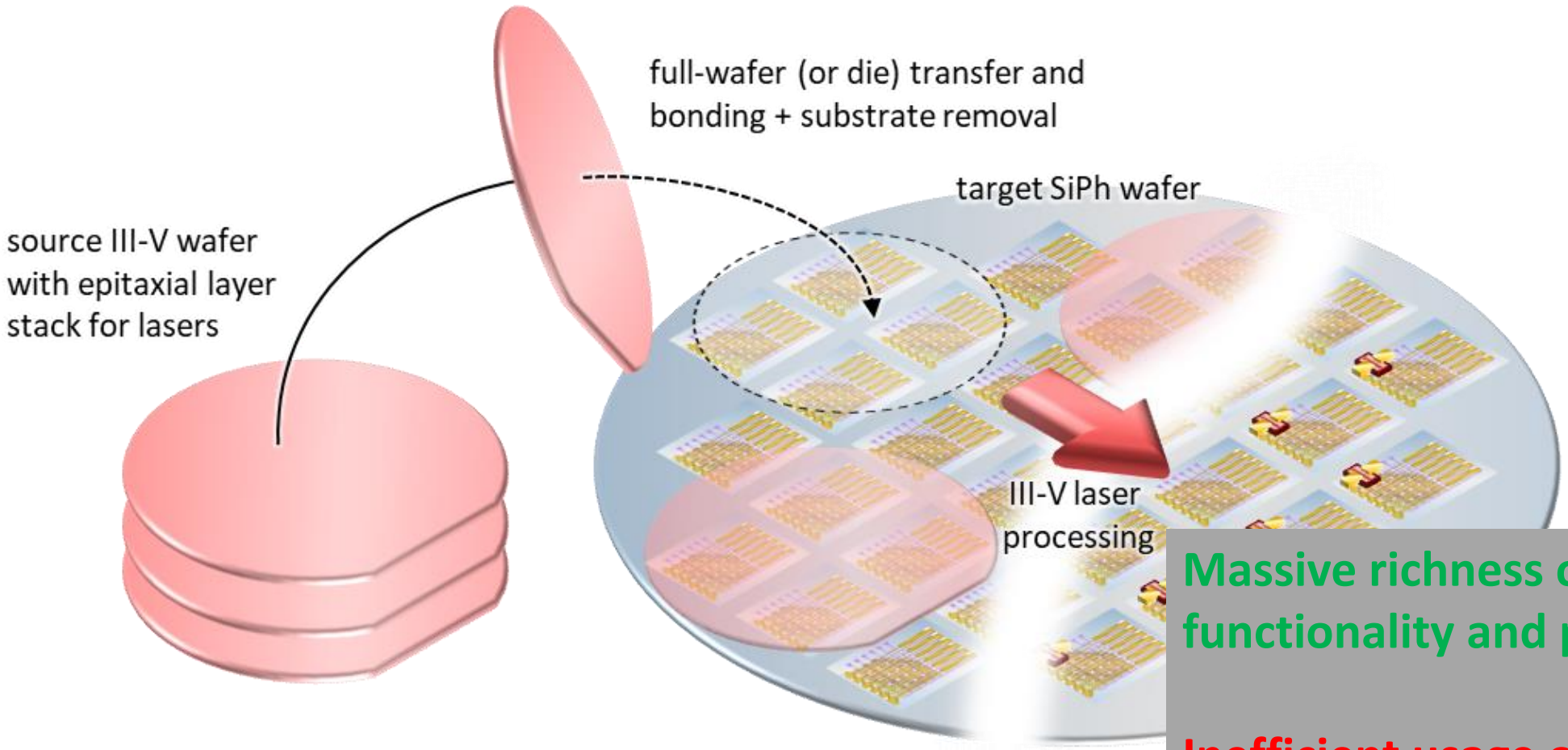


Mature for products today
Known good die

Not scalable to very low cost
SOAs are challenging

Approaches to hybrid III-V integration on SiPhotonics

die-to-wafer and wafer-to-wafer bonding + III-V processing in silicon fab



Massive richness of functionality and performance

Inefficient usage of III-V
Very high NRE costs

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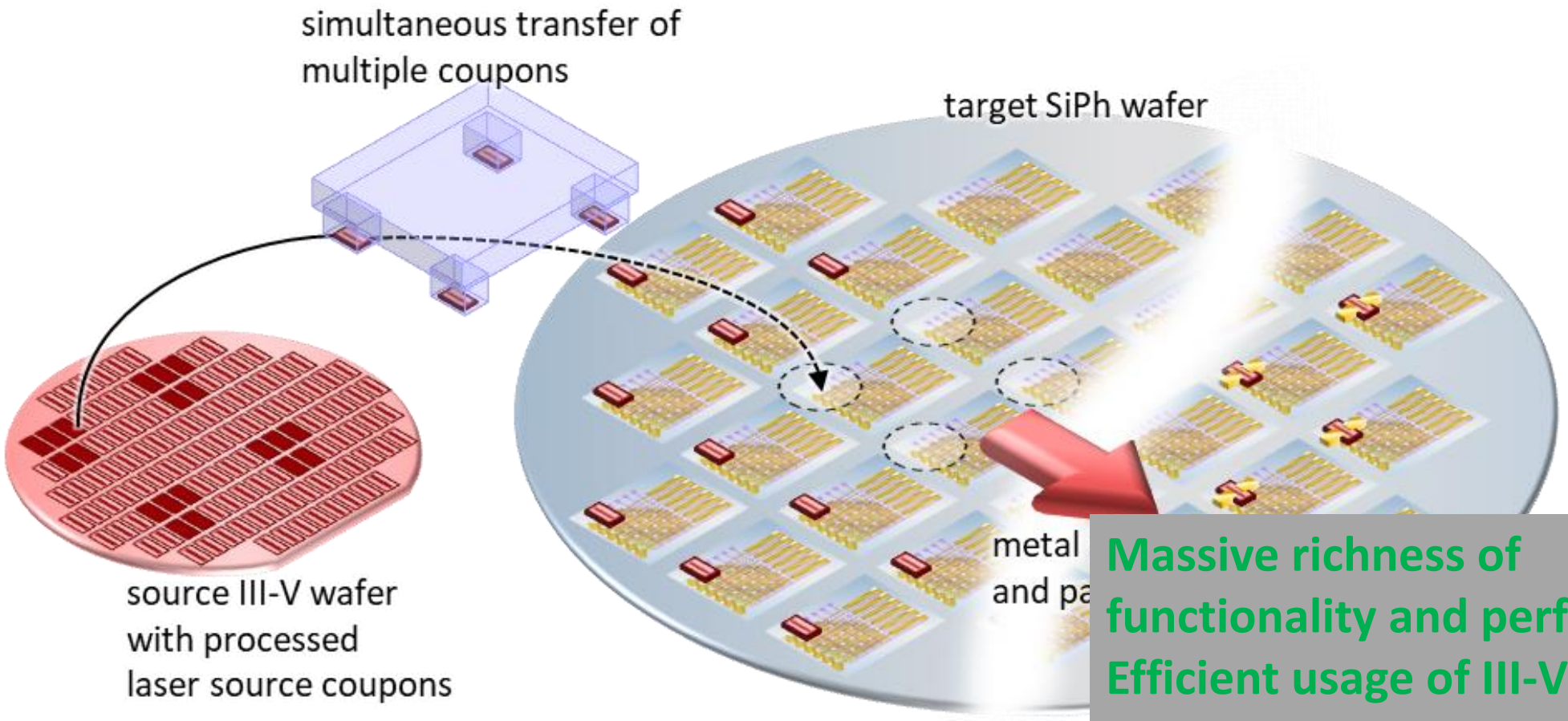
Approaches to hybrid III-V integration on SiPhotonics

Transfer printing



Massive richness of functionality and performance
Efficient usage of III-V
Low cost
Reliability to be proven

TAKE-HOME MESSAGE

There is a large diversity in approaches for light source integration in silicon photonics

Some are in commercial products today (flip-chip, bonding)

Others are very much at the research level (epitaxy, transfer printing)

The hunt is still open for a method, implemented in an industrial foundry, that combines scalability to high volume and low cost with high long-term reliability

OUTLINE

ePIXfab

The options for light source integration

Work in progress in Europe

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ePIXfab

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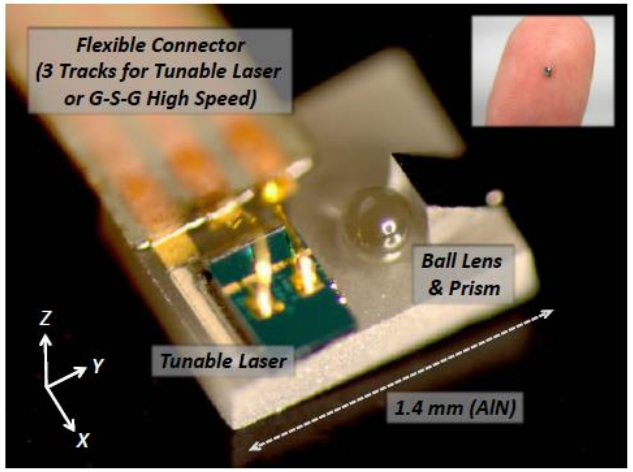
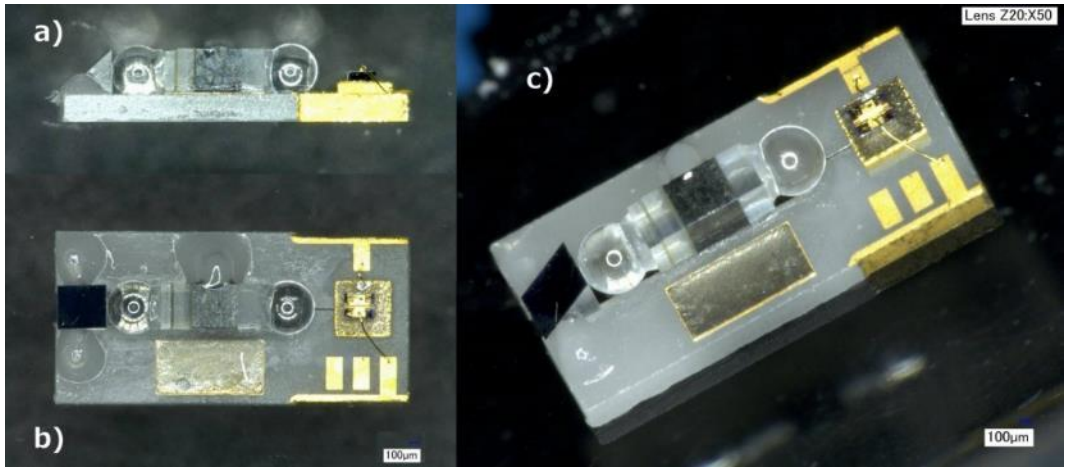
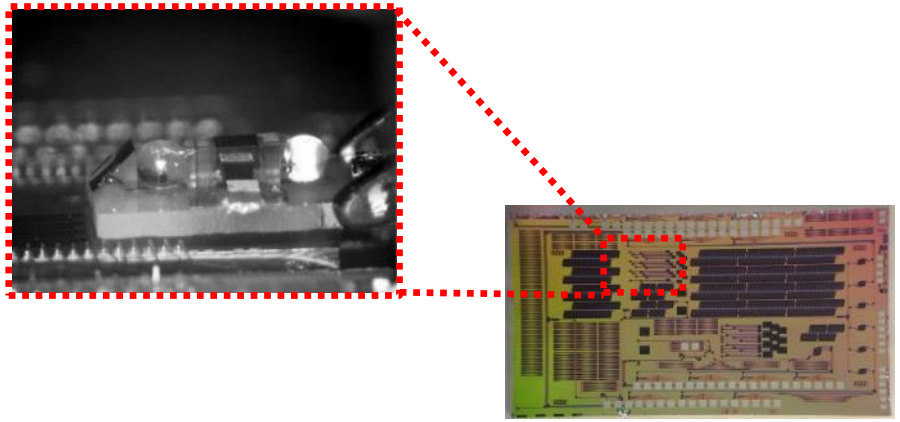
Pick-and-Place Laser Integration – Edge Emitters



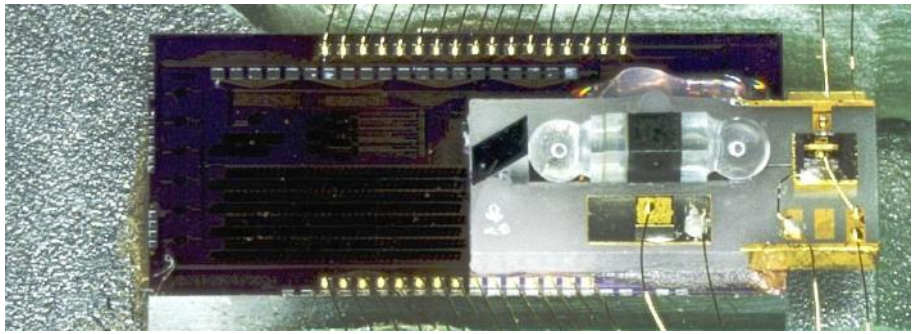
Standard Micro Optical Bench



Micro Optical Bench with Isolator

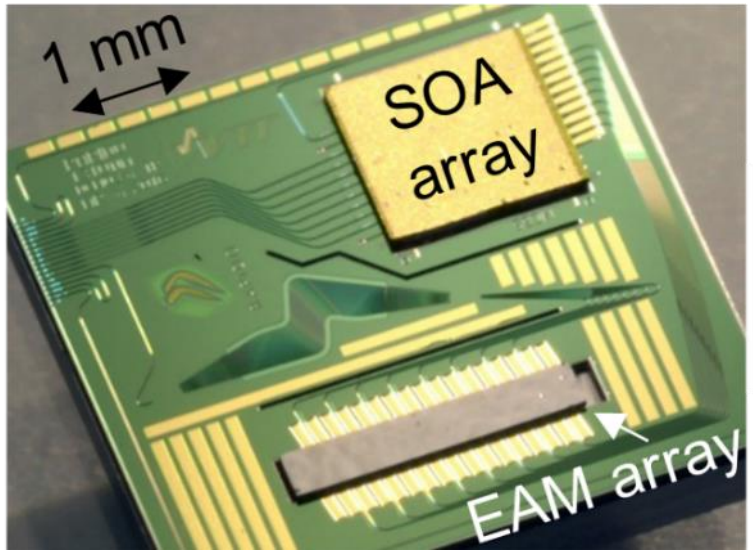


Assembly

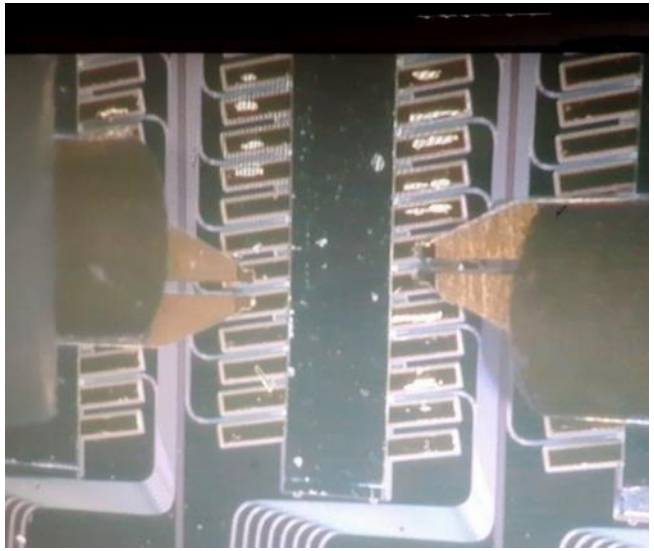


Hybrid integration of active components on 3 µm SOI platform

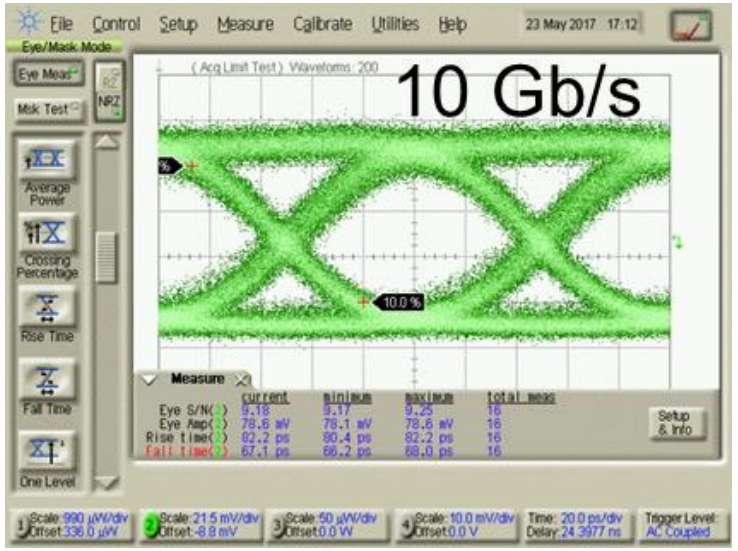
- Lasers, amplifiers, modulators and photodetectors have been flip-chip bonded on 3 µm SOI using Au-Au thermo compression bonding



5x5 mm SOI chip with 8-ch SOA and EAM arrays



EAM array being tested on SOI



InP EAM test result

OUTLINE

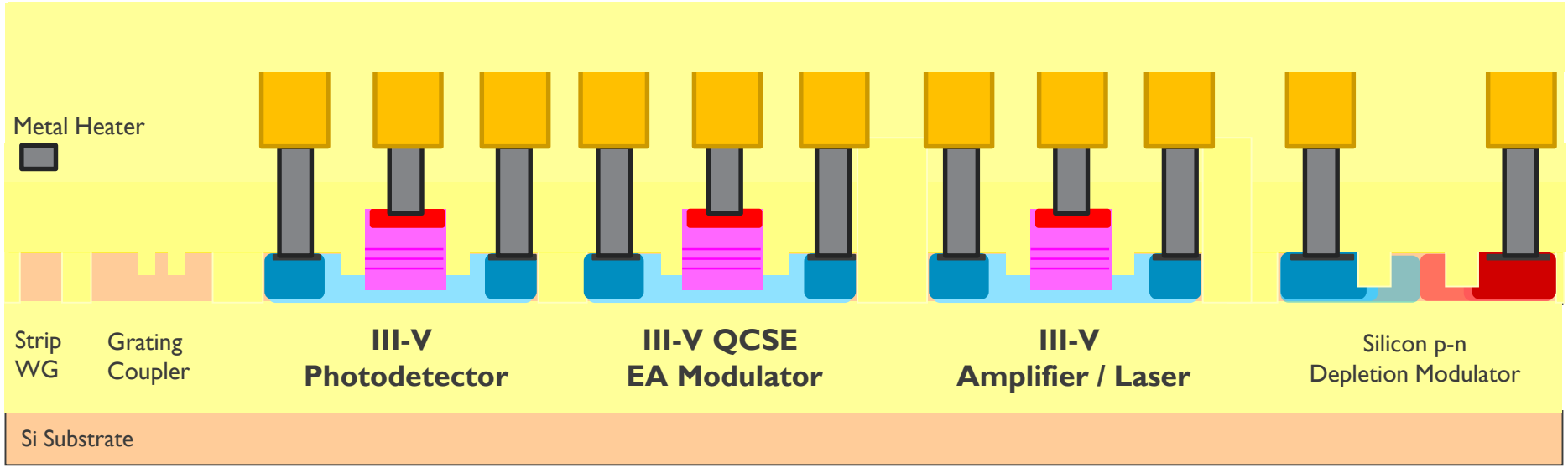
ePIXfab

The options for light source integration

Work in progress in Europe

- Short term to market
- ➡ Long term to market
- Medium term to market

Silicon Photonics 2.0 – Proposed Cross Section

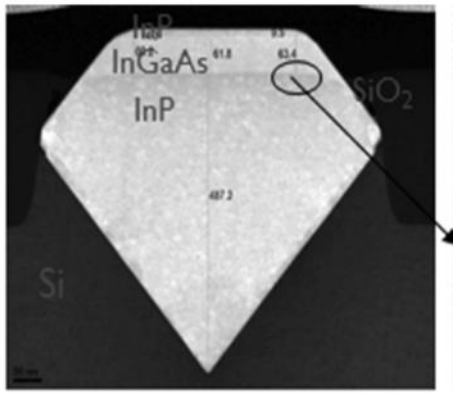


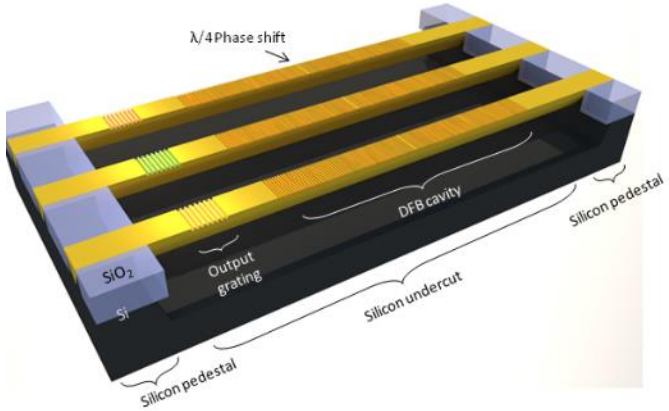
Our long-term objectives for ***monolithic III-V on Si lasers****:*

- Wafer-scale fabrication in 300mm CMOS fab: MOVPE
- Integrated in a silicon passive/active PIC → selective area growth
- Electrically driven, with high wall-plug efficiency (>10%)
- Efficient coupling to Si waveguide (<0.5dB)
- High temperature operation (>85C)
- High reliability, long lifetime → TDD <$10^6 cm^{-2}$?
- Emission wavelength in O-band (datacom) or C-band (telecom)

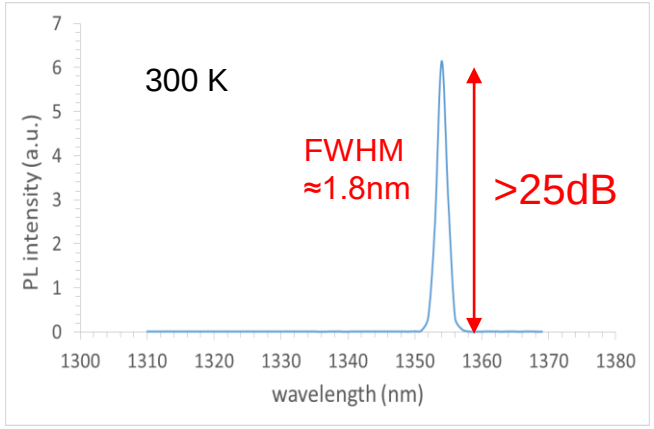
Rapid Progress on III-V on silicon hetero-epitaxy

O-pumped InP DFB lasers (RT) @ imec

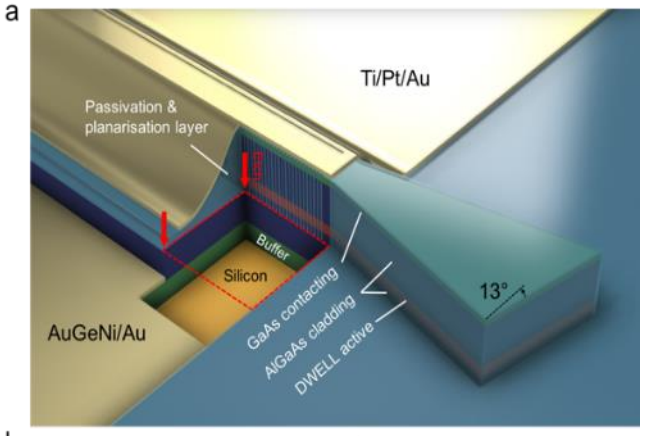


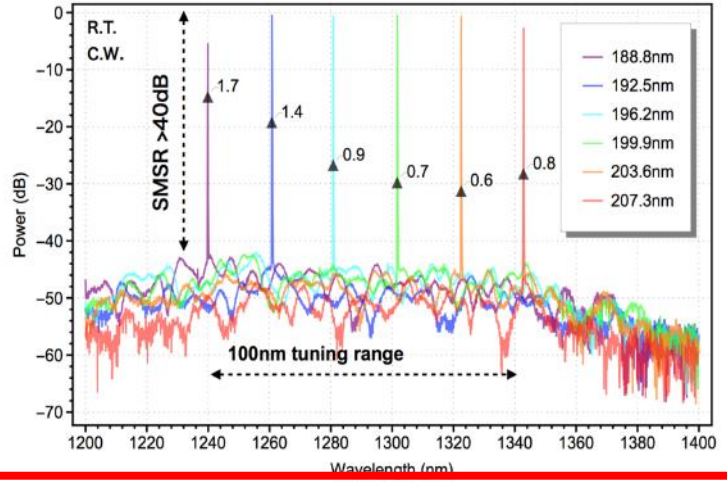


Laser emission spectra

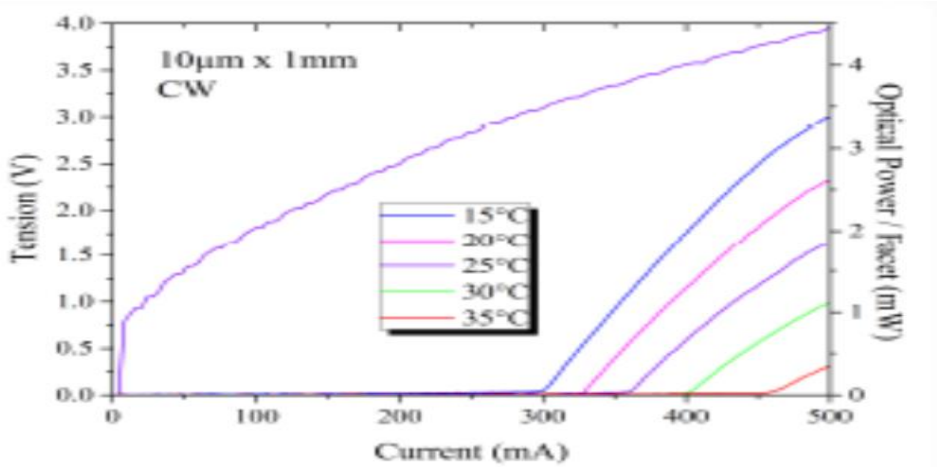


E-pumped QD DFB lasers (RT, CW) @ UCL





E-pumped GaSb QW lasers (RT) @ U.Montpellier



Remaining big challenge: integration in the SiPh process flow

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OUTLINE

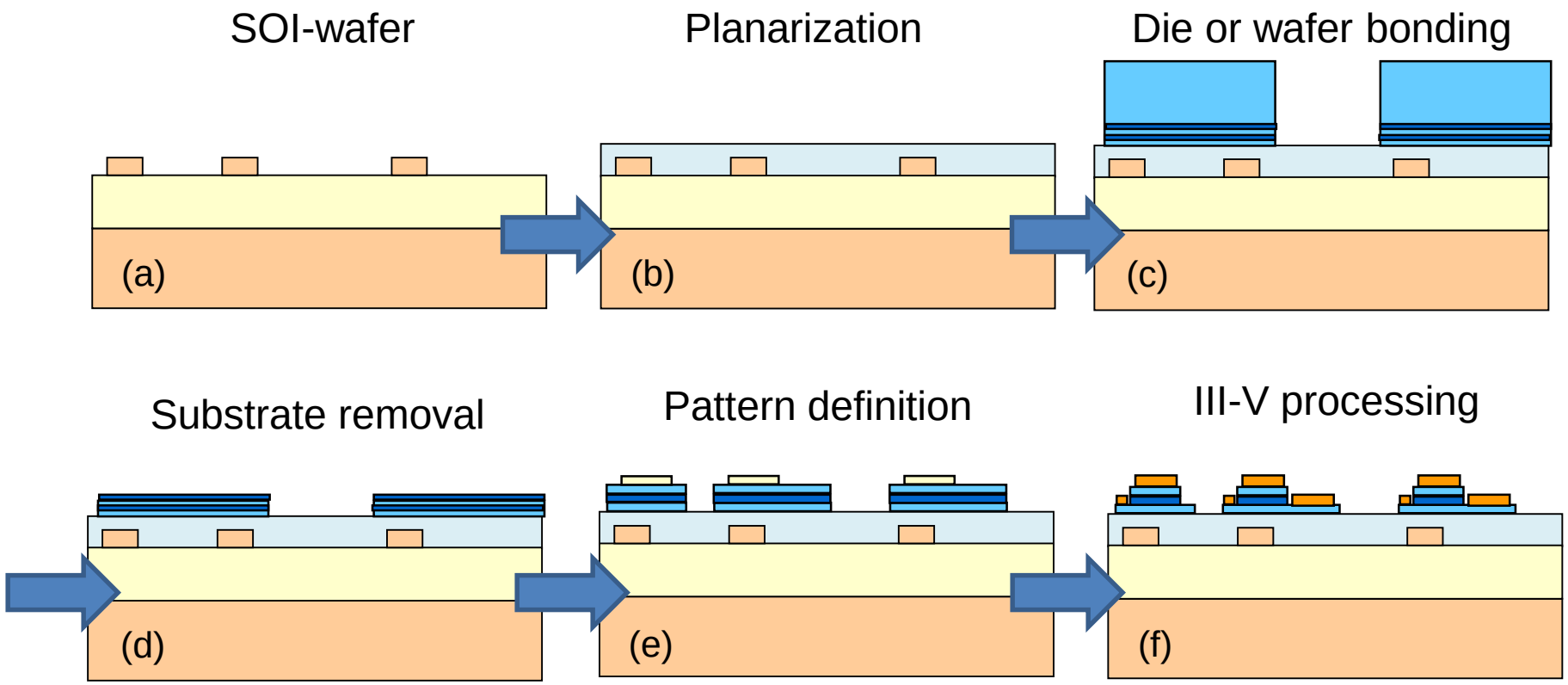
ePIXfab

The options for light source integration

Work in progress in Europe

- Short term to market
- Long term to market
- ➡ Medium term to market

III-V-on-silicon die-to-wafer bonding



III-V INTEGRATION ACTIVITIES IN LETI

Motivation:

- Large scale integration of III-V based device on CMOS compatible silicon photonic platform

Components:

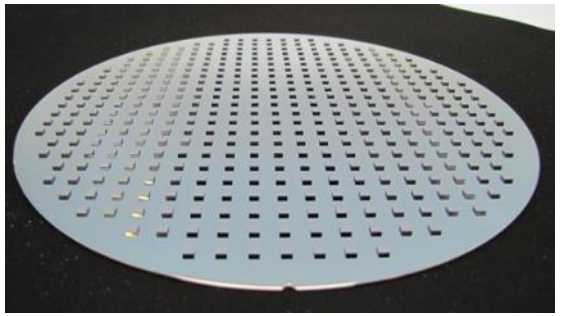
- Laser
- Electro-absorption modulator
- Semiconductor optical amplifier

Specific process module developments:

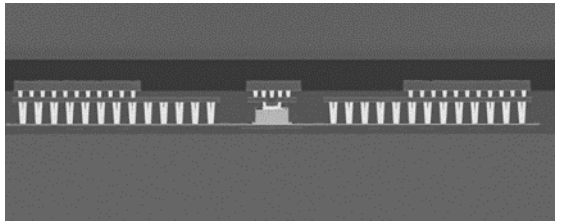
- Multi-die bonding on patterned SOI wafers
- **III-V patterning on 200 & 300mm wafers**
- **III-V contacts with cmos compatible materials**
- Back side integration

References:

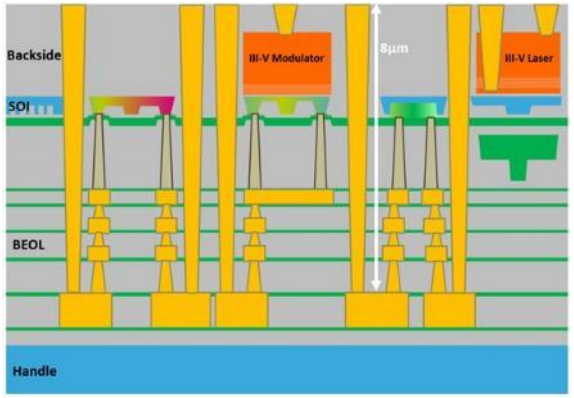
A.Descos et al, ECOC 2013
H. Duprez et al, Opt. Express 23(7), 8489 (2015)
T. Ferrotti et al, SSDM 2016
B. Szelag et al, IEDM 2017
K. Hassan et al, SSDM 2018



Die Bonding on 200 & 300mm Si wafers

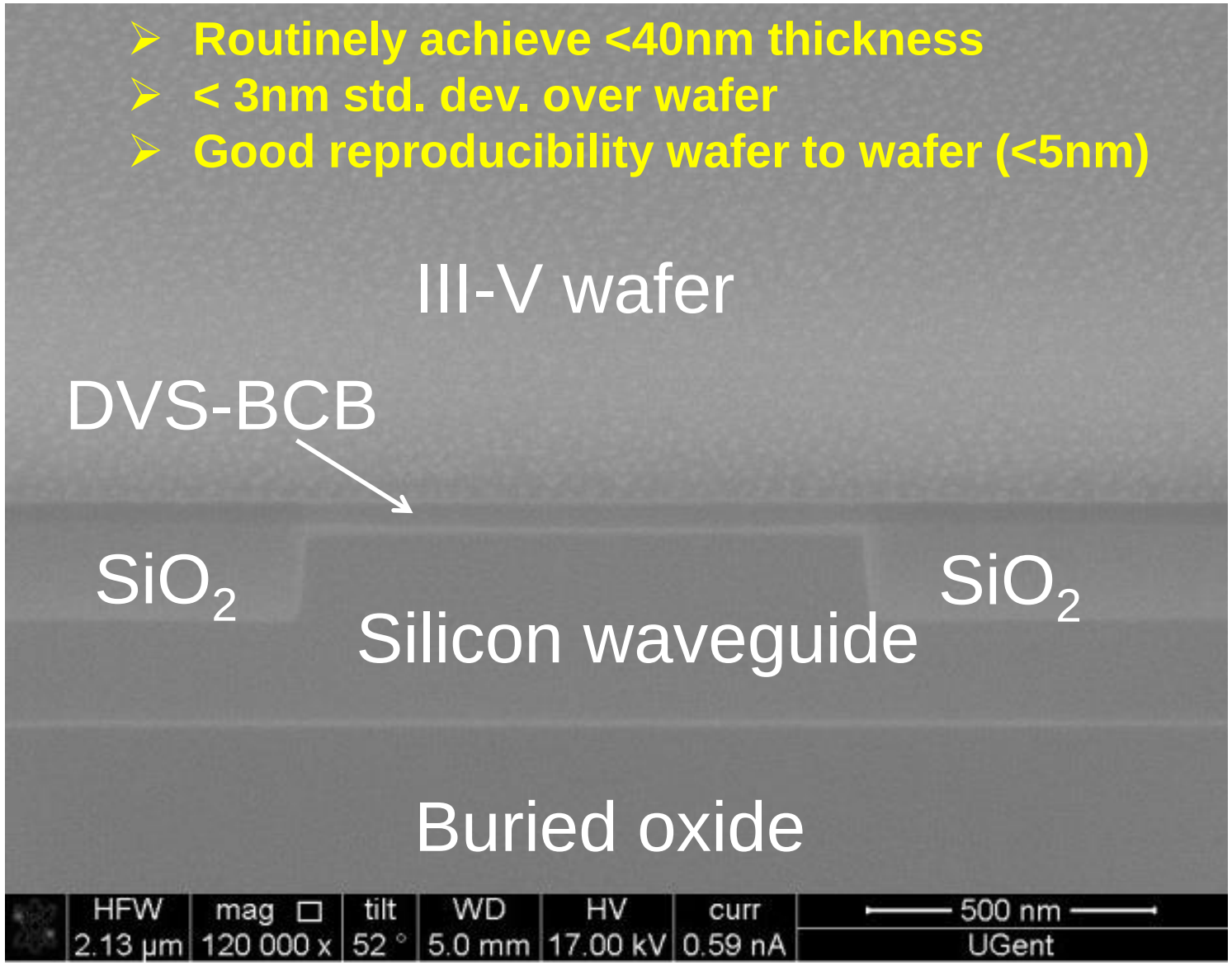


III-V/Si Laser with multilevel planar BEOL

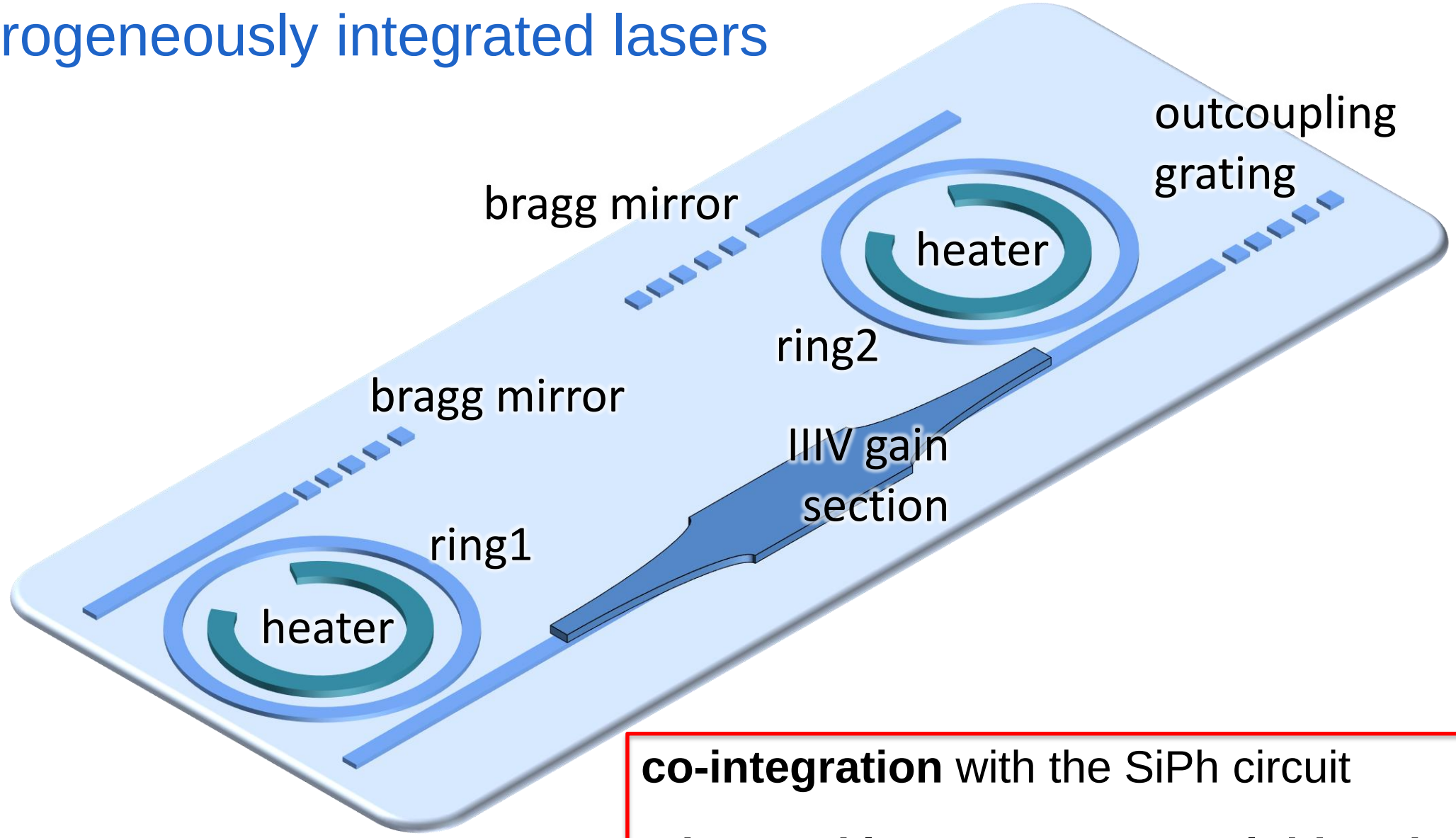


III-V/Si components integrated on backside of a complex photonic platform

III-V-on-silicon die-to-wafer bonding



Heterogeneously integrated lasers



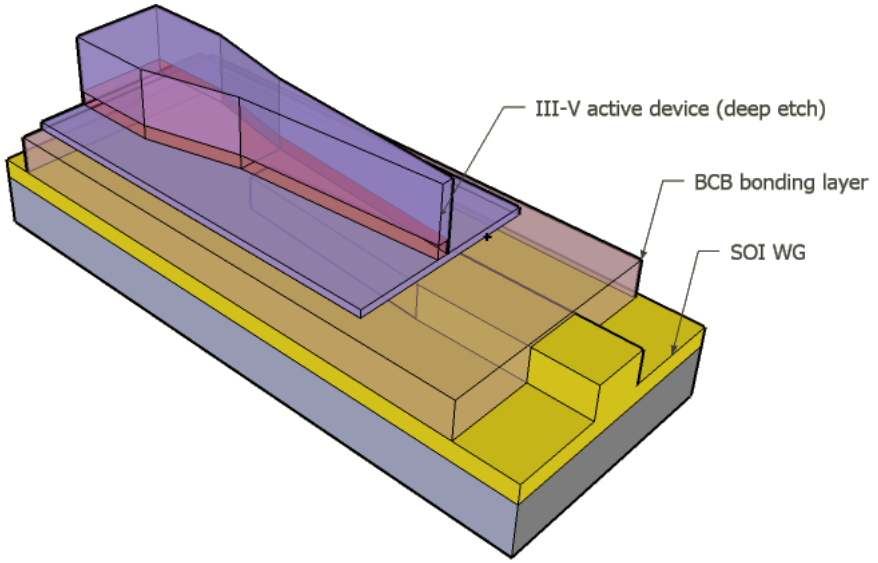
co-integration with the SiPh circuit

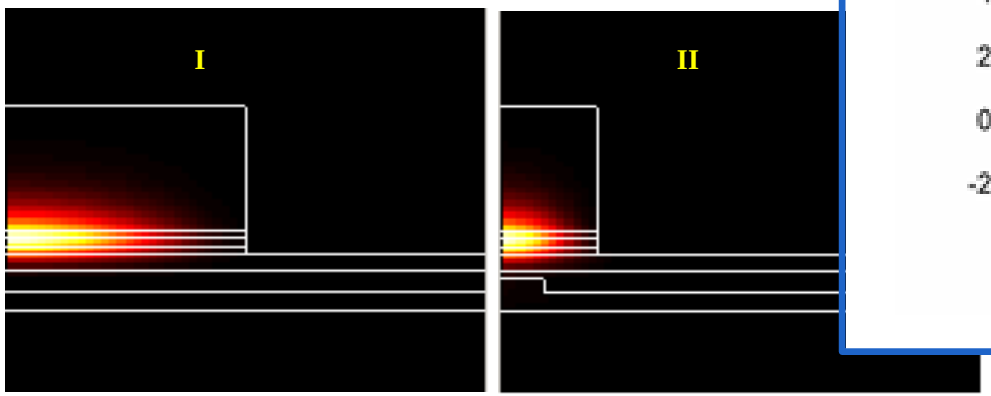
advanced laser sources exploiting the high performance Si passive functions

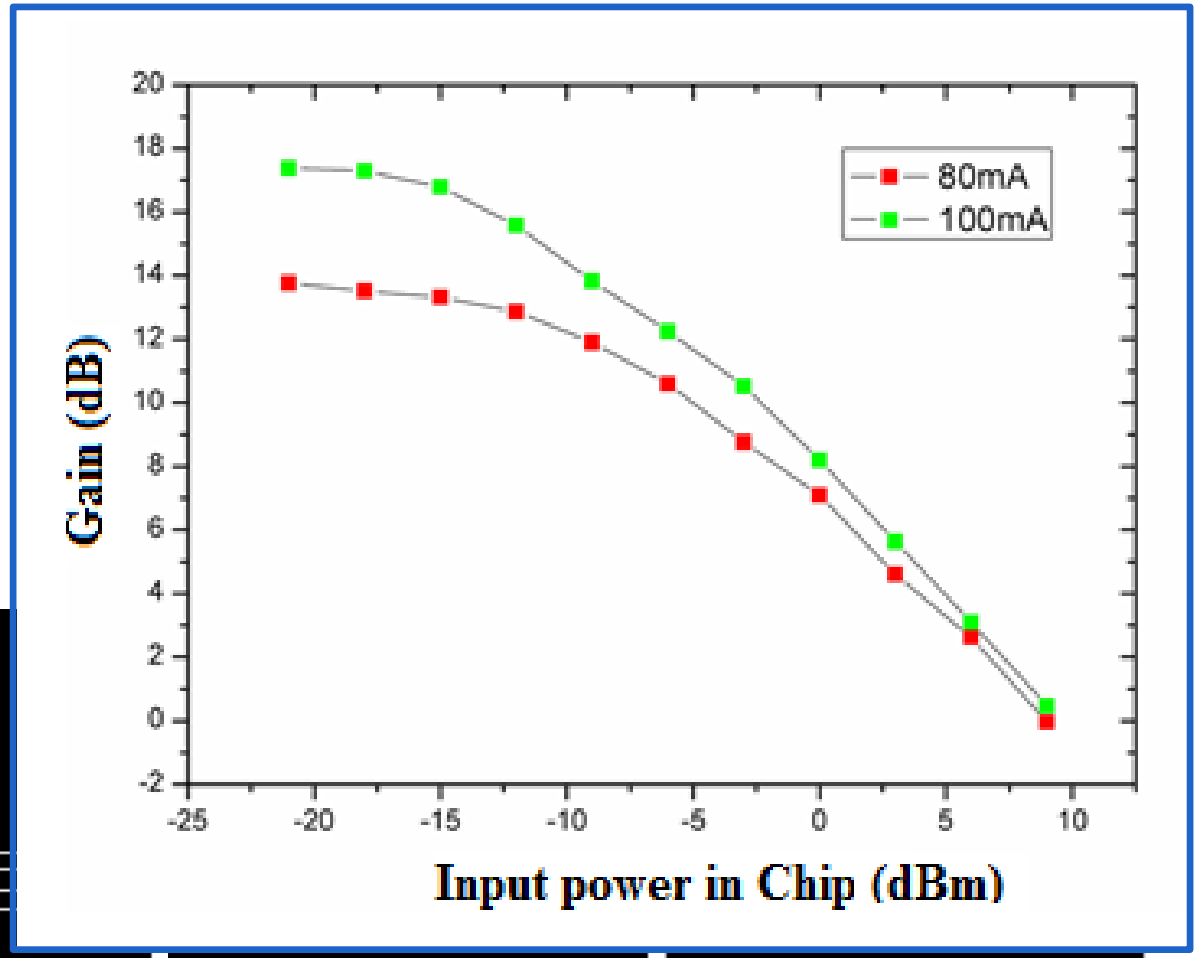
InP-on-Si C-band lasers – SOAs

No exposed facets
Intrinsically hermetically sealed

From full confinement in III-V to full confinement in SOI



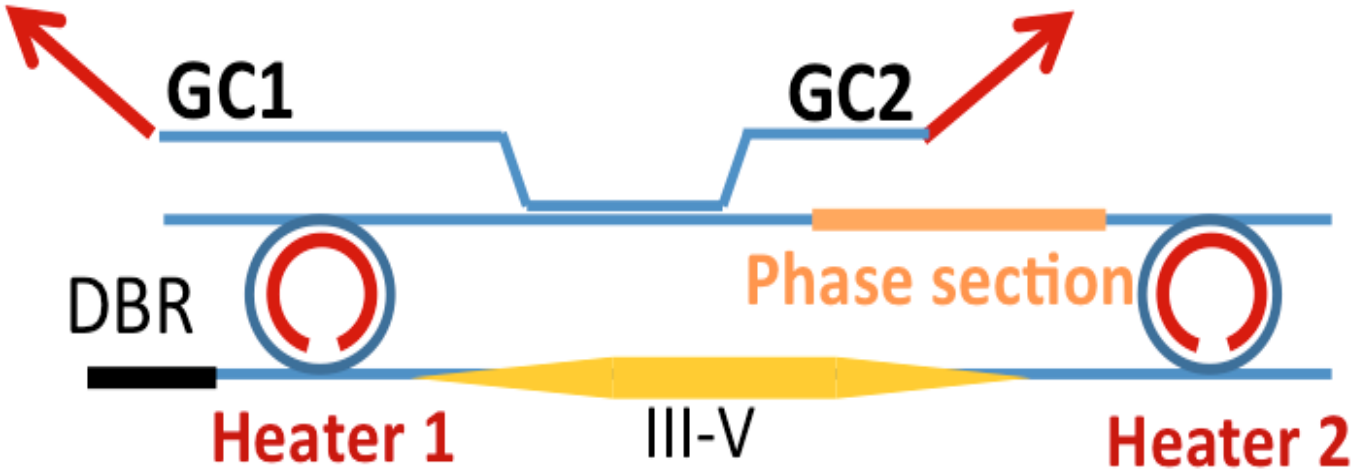




Fundamental mode in different cross-sections (BCB thickness=80nm)

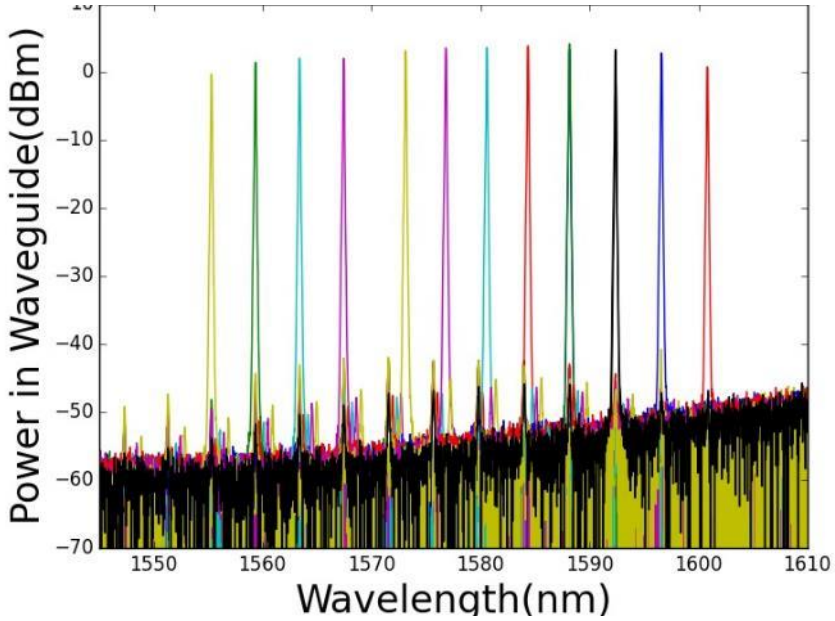
31

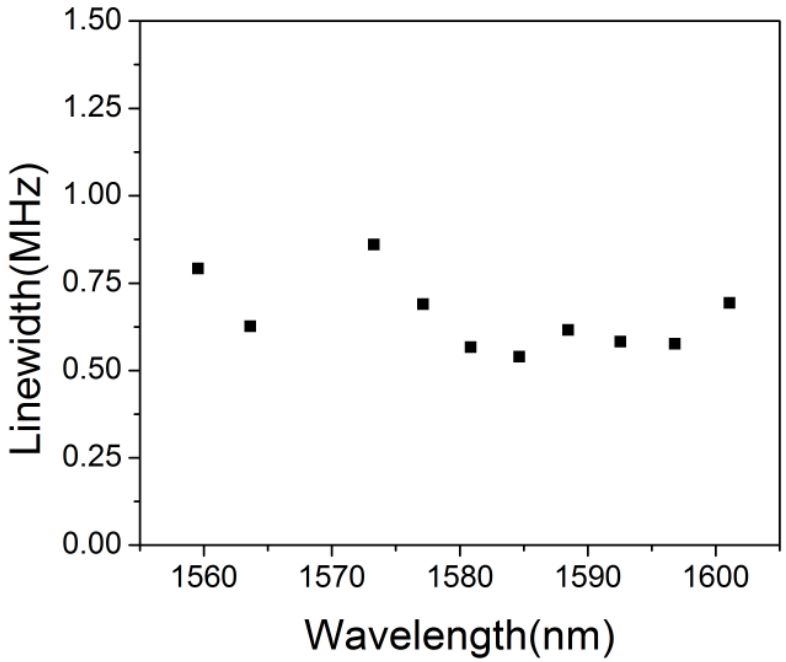
InP-on-Si C-band lasers – widely tunable lasers



Using Vernier ring resonator filter wavelength tuning can be realized together with narrow linewidth

Including a DBR couples CW to CCW – leading to unidirectional operation

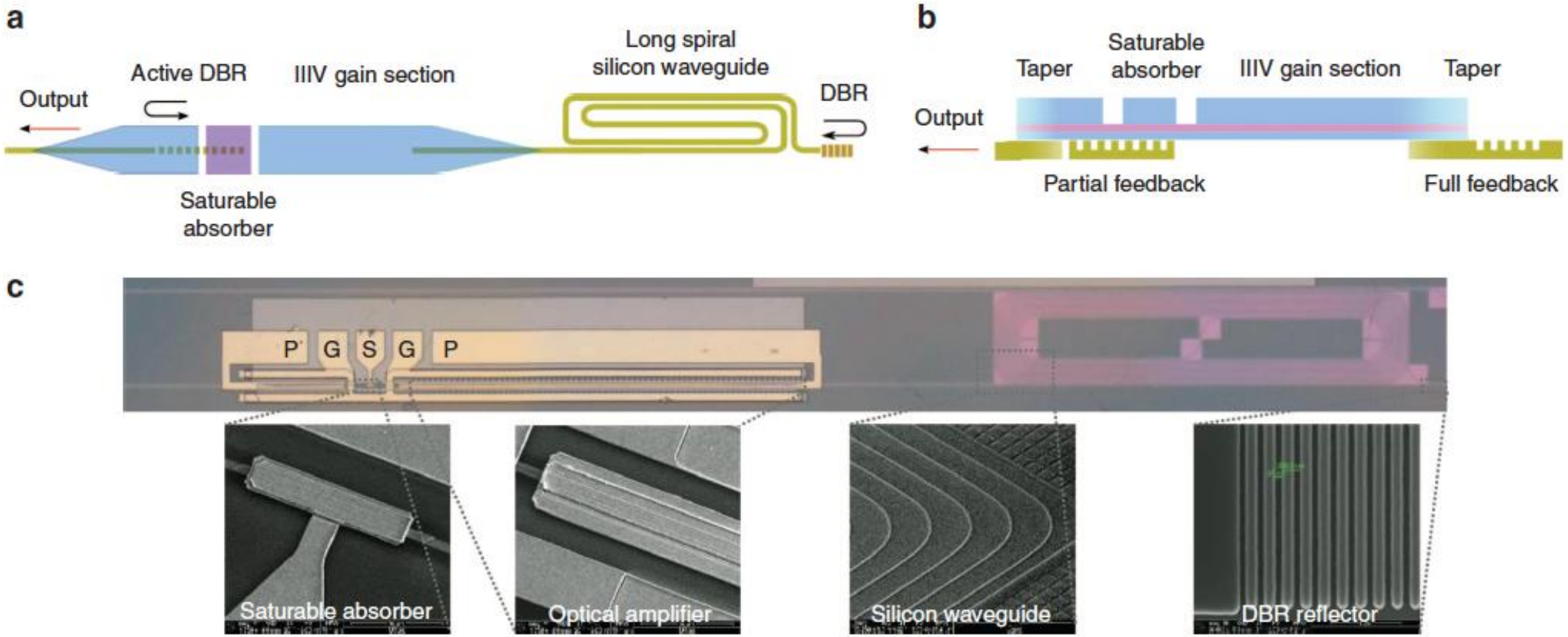




45 nm tuning range- SMSR > 40 dB

Linewidth between 500kHz and 850 kHz

InP-on-Si C-band lasers – modelocked laser

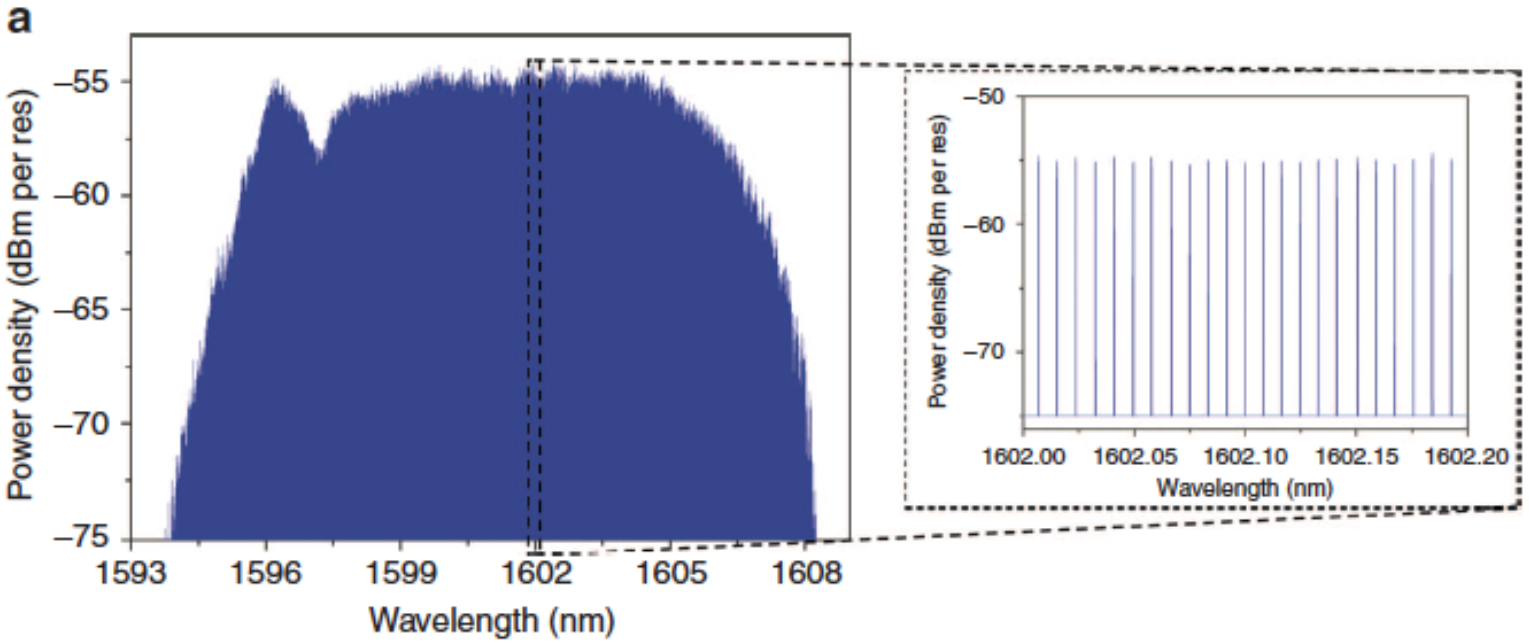


- 1GHz repetition rate modelocked laser (lowest rep rate obtained on integrated platform)
- III-V gain section, III-V saturable absorber & long Si waveguide (0.7dB/cm loss) to form the laser cavity

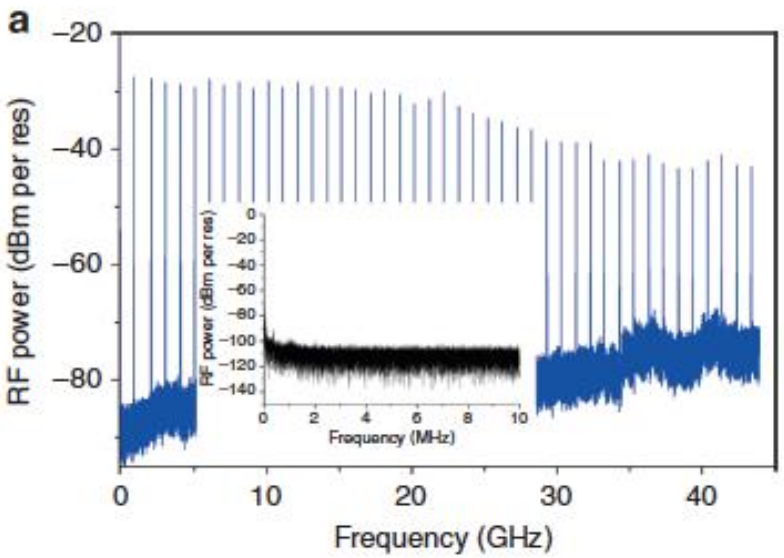
InP-on-Si C-band lasers – modelocked laser

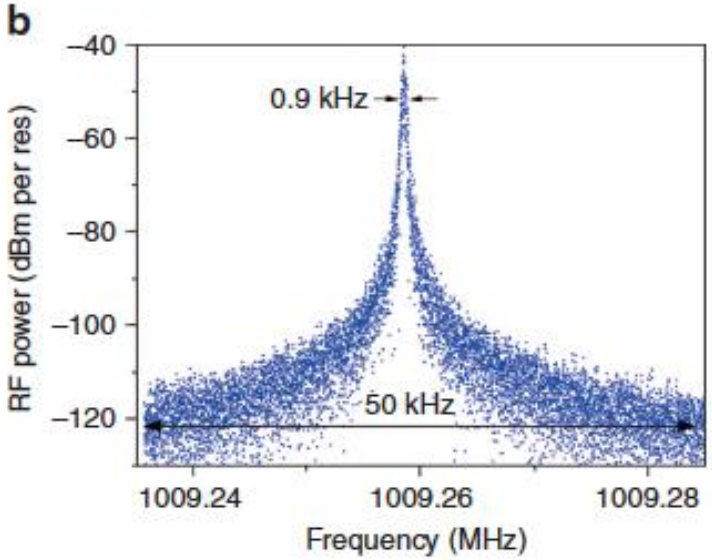
Passive modelocking

Optical spectrum



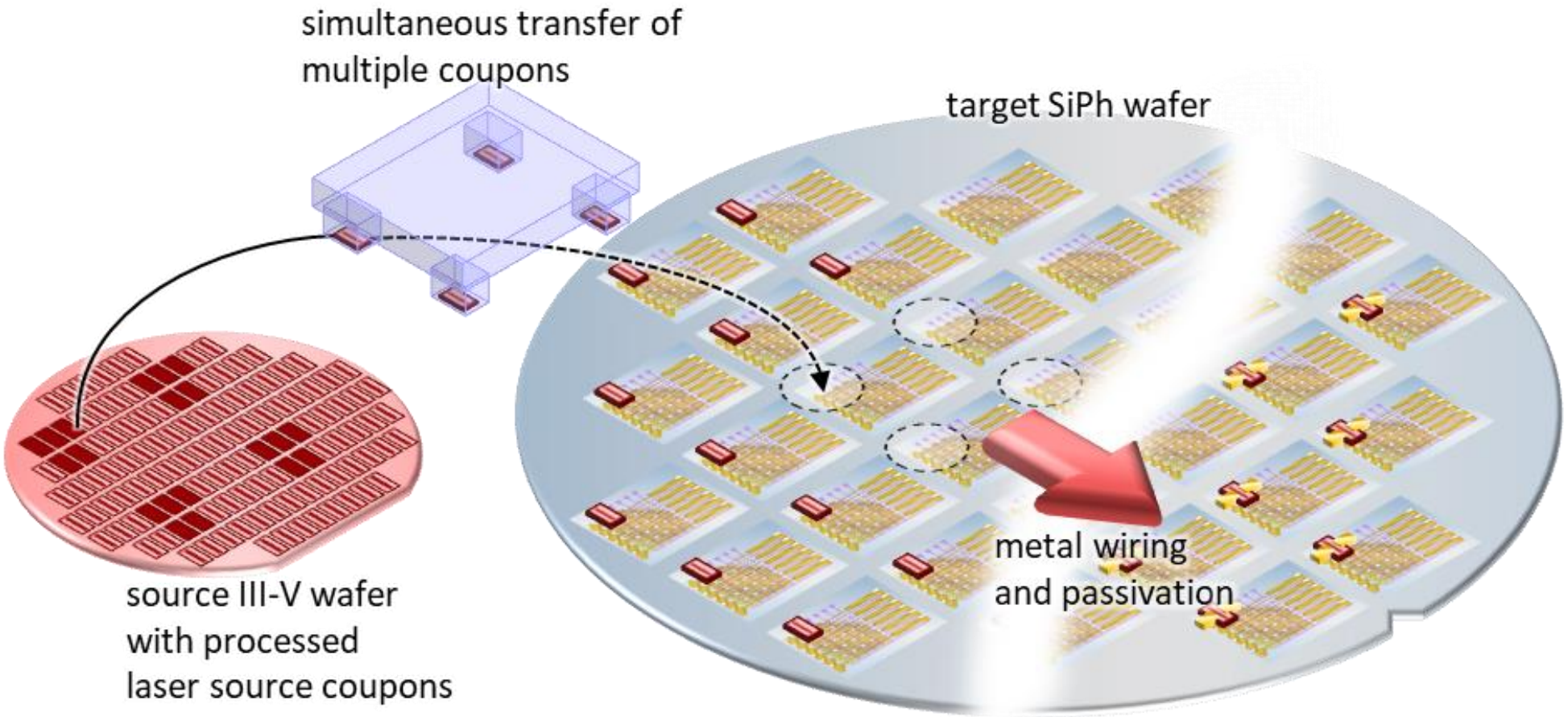
RF spectrum





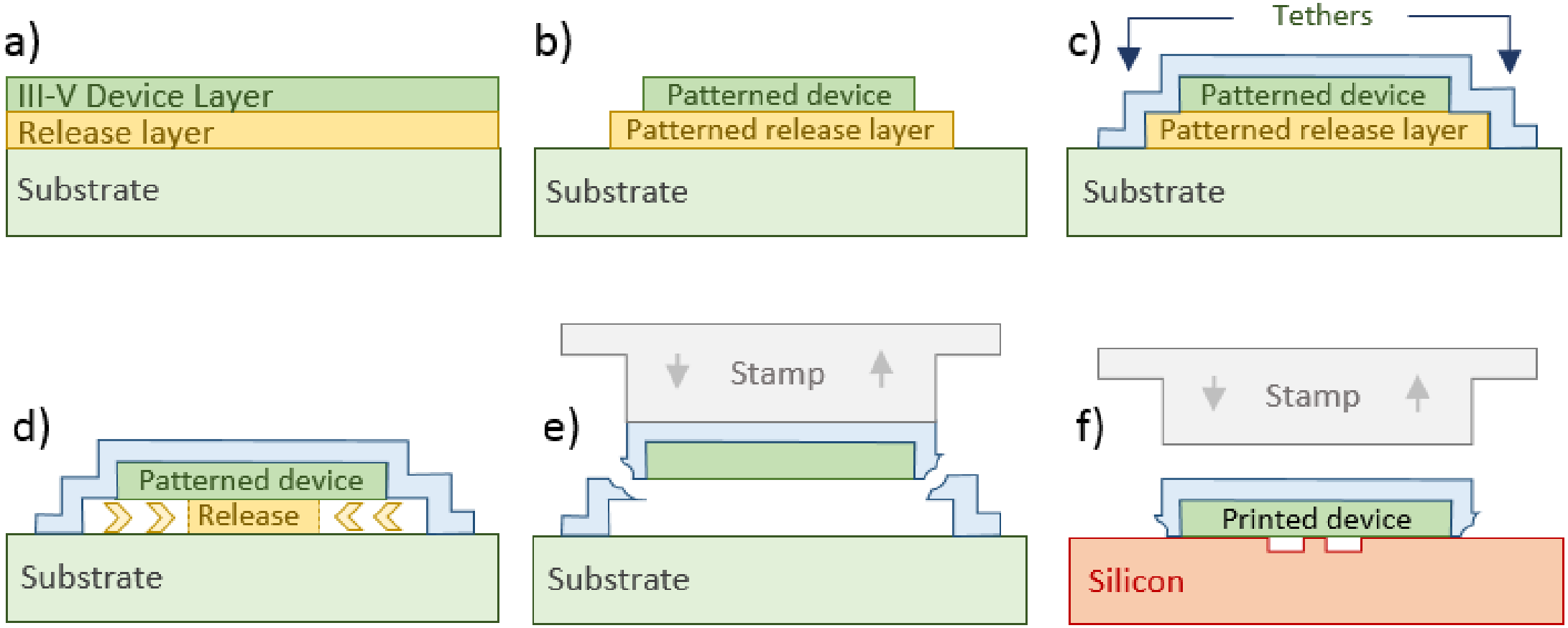
Approaches to hybrid III-V integration on SiPhotonics

Transfer printing



Combines advantages of pick-and-place/flip-chip/wafer bonding

Transfer printing for III-V-on-silicon integration



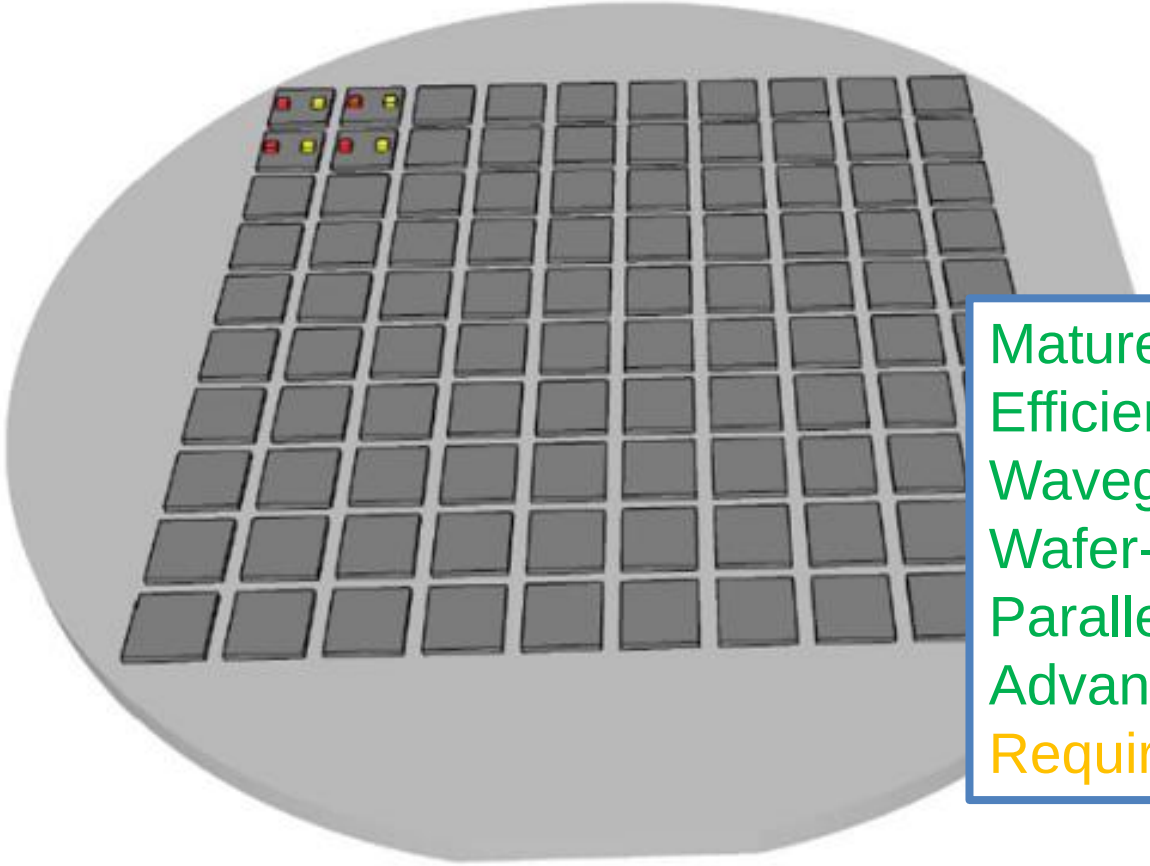
Transfer of micro-scale III-V devices to a SiPhotonics target wafer

Transfer printing for III-V-on-silicon

AREA MAGNIFICATION
DENSE INTEGRATION

PDMS stamp

III-V source wafers

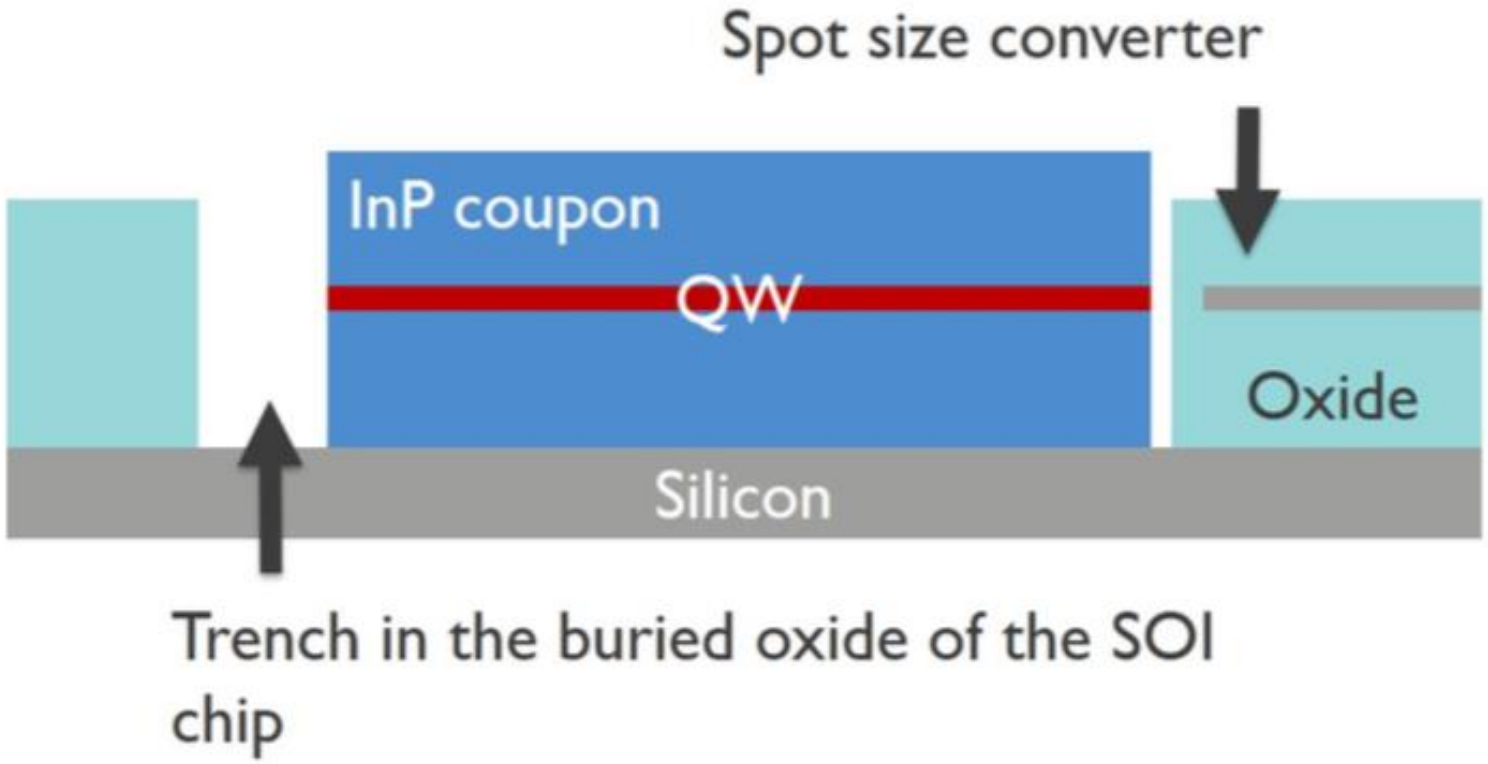


SOI target wafer

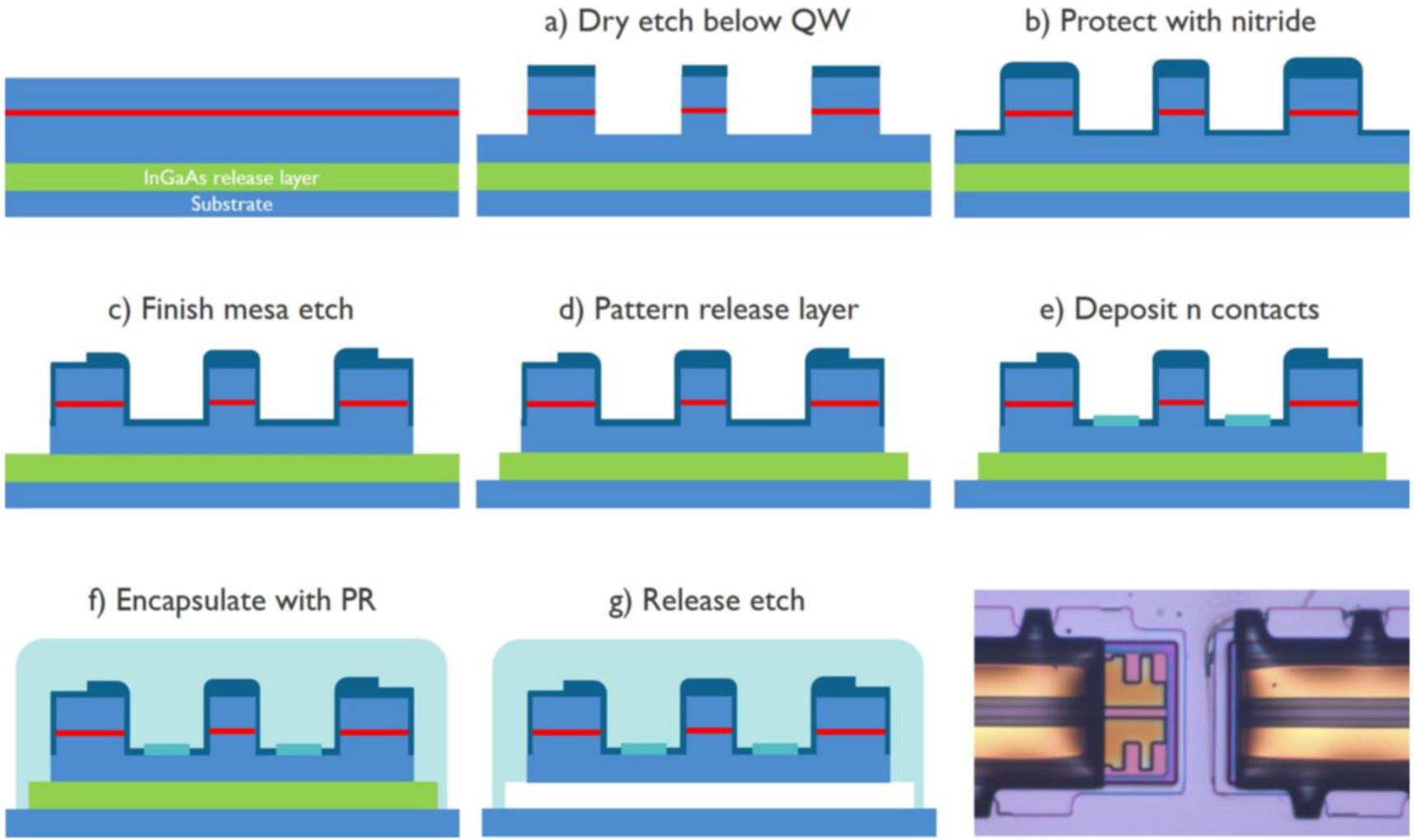
Mature InP processing
Efficient optical coupling possible
Waveguide in-out devices (SOA)
Wafer-level test on source wafer
Parallel assembly of devices
Advanced laser sources
Requires local back-end removal

1 inch stamp size
30 sec per print cycle

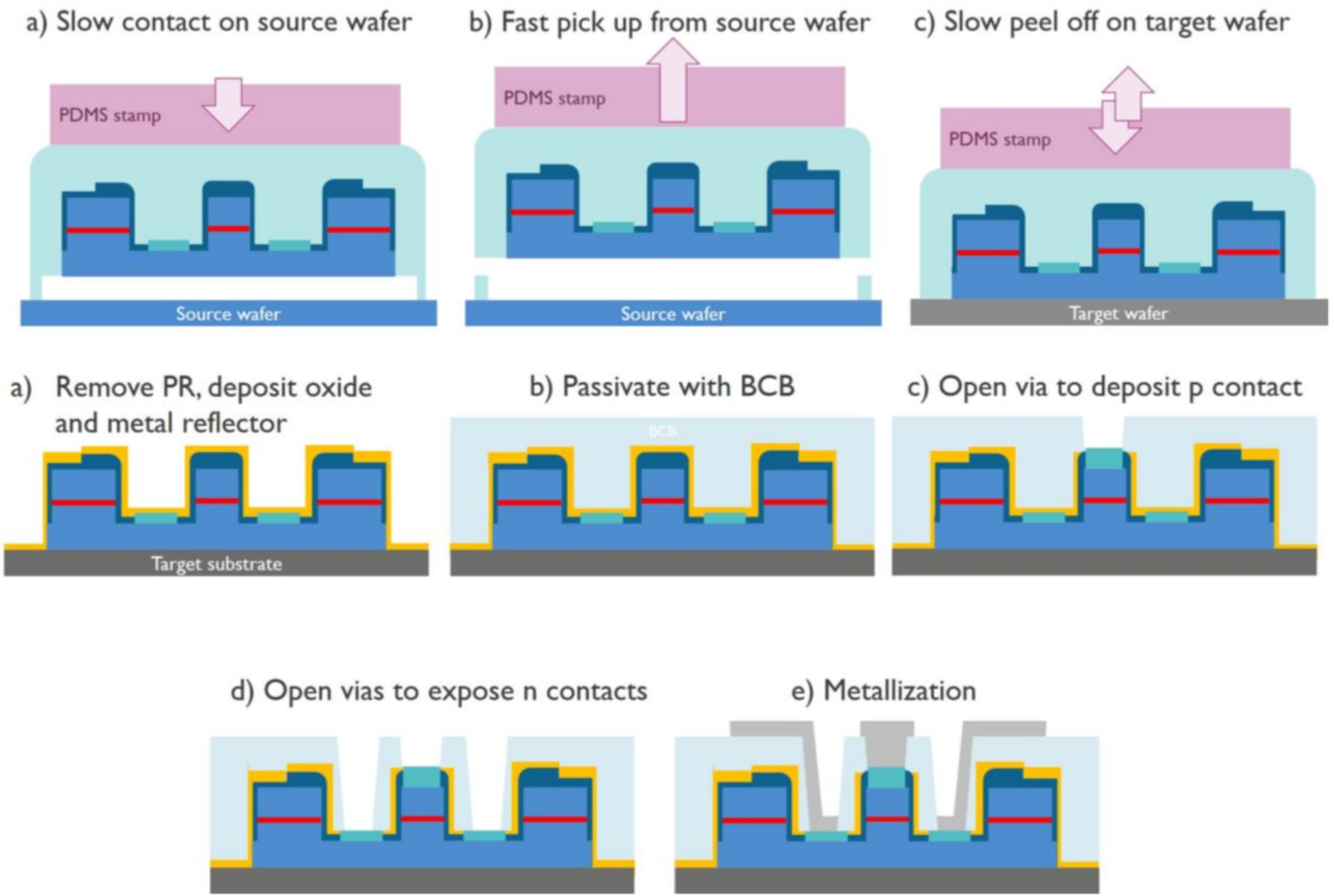
TRANSFER PRINTING OF ARRAYS OF LASERS



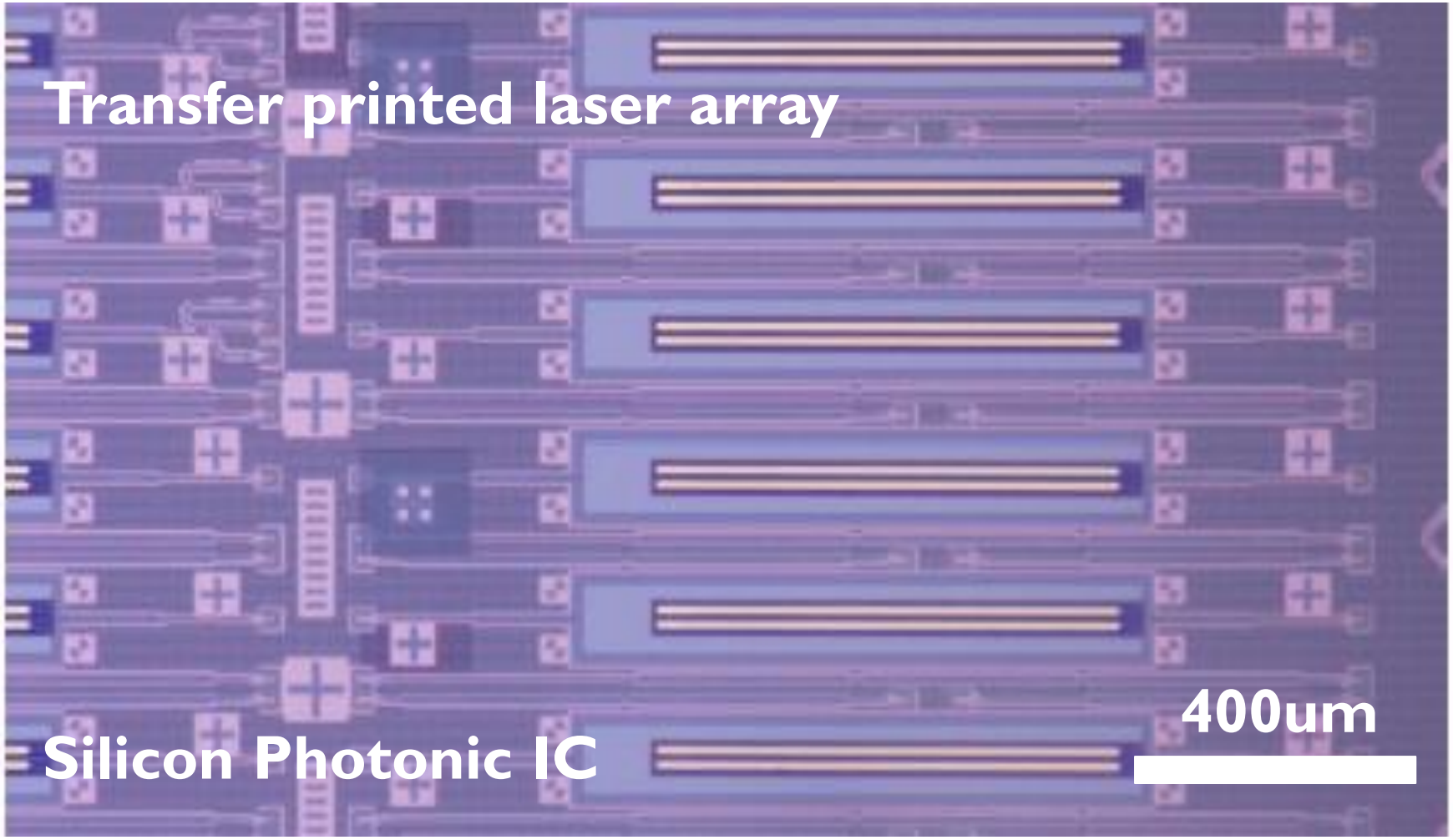
TRANSFER PRINTING OF ARRAYS OF LASERS



TRANSFER PRINTING OF ARRAYS OF LASERS



TRANSFER PRINTING OF ARRAYS OF LASERS

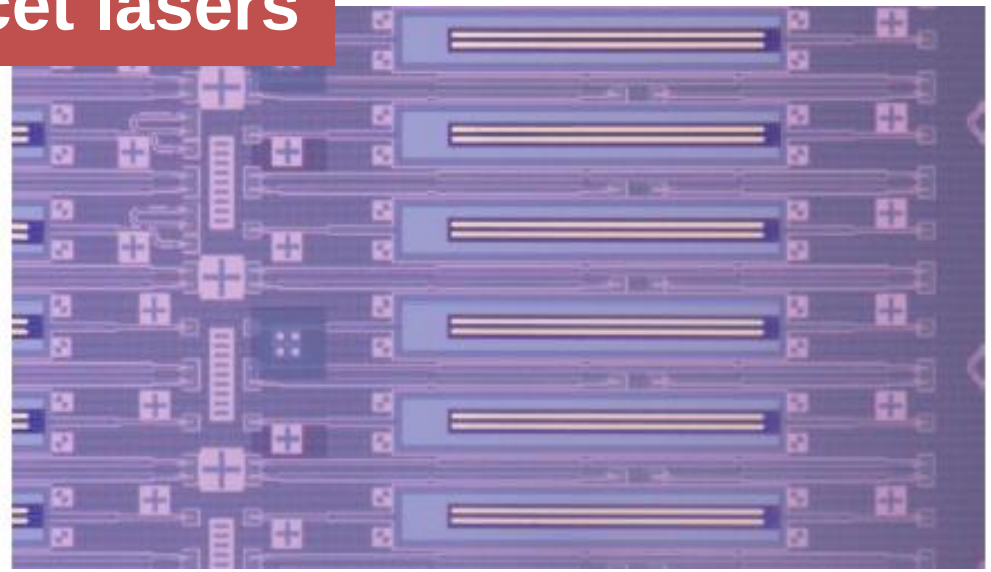


Transfer printing: versatile integration

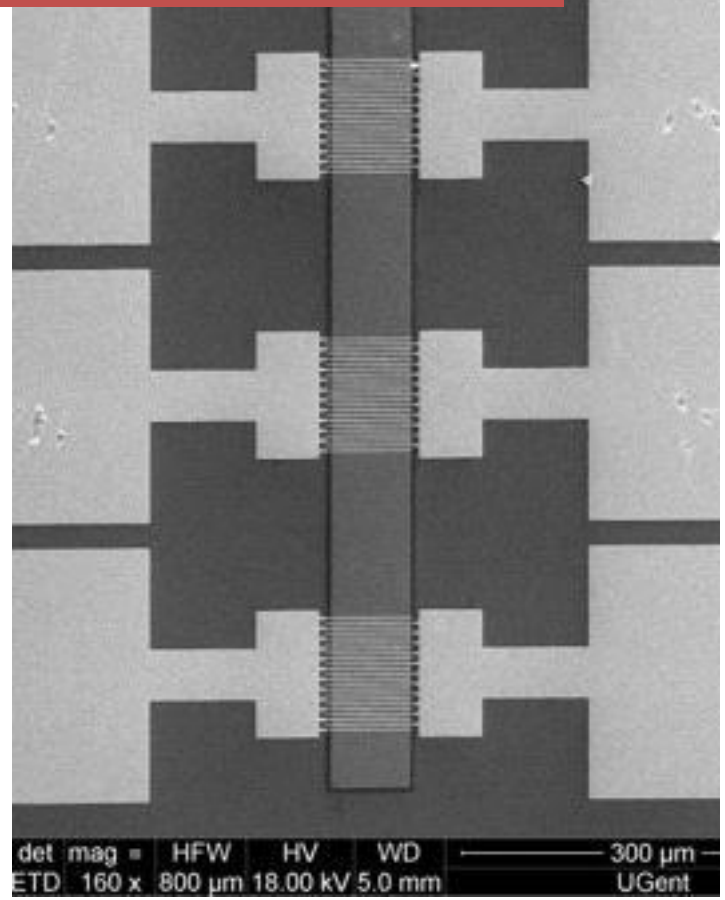
FAB MIXED-SIGNAL FOUNDRY EXPERTS

Tyndall National Institute

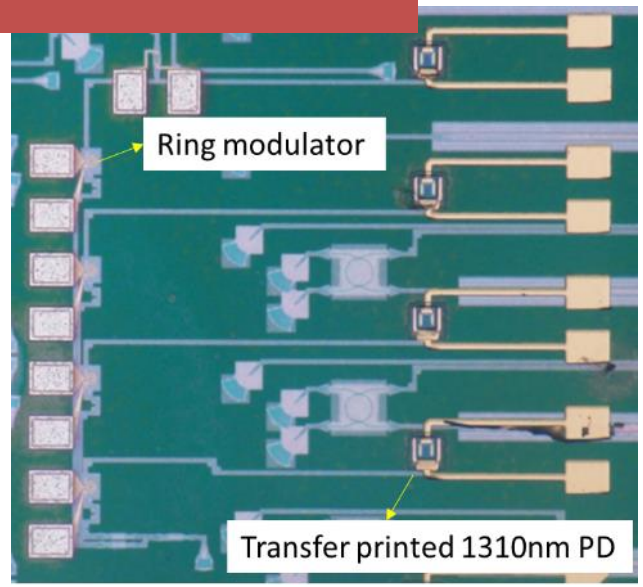
Etched facet lasers



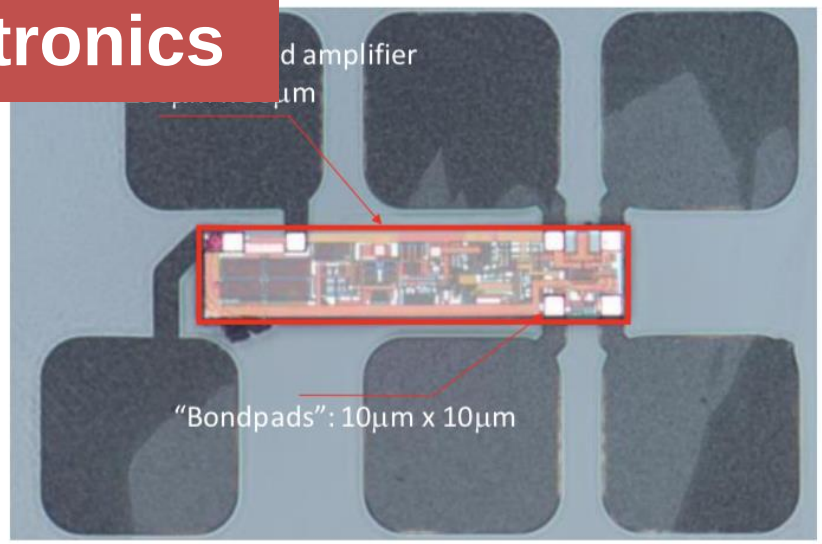
2D/0D materials



photodiodes



electronics



etc. etc…

GHENT UNIVERSITY imec

Conclusions

- Silicon photonics: is in the market with a diversity of “flavours”
- Light source integration:
  - Many options
  - Exciting and very fast scientific progress
  - But few options have an open-access industrial supply chain today
  - This will likely change in the next few years

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