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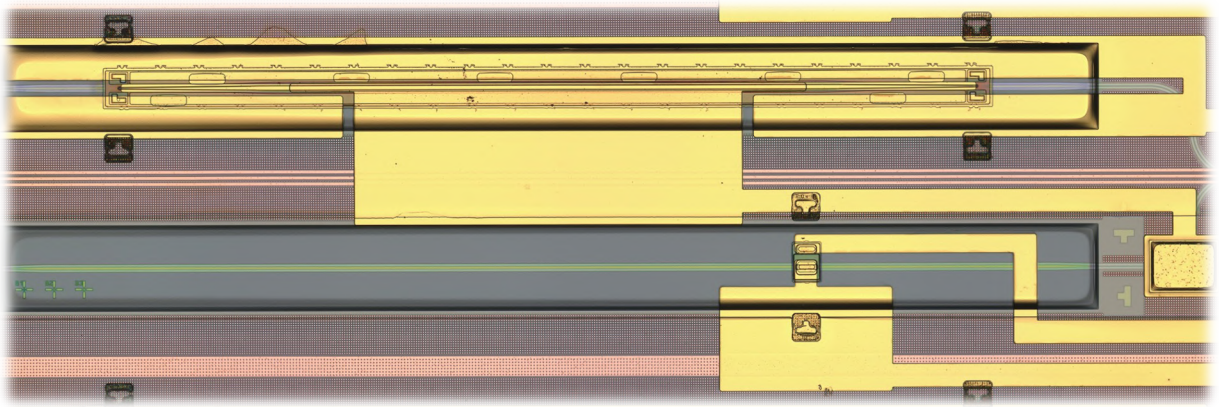
DEPARTMENT OF INFORMATION TECHNOLOGY (INTEC) – **PHOTONICS RESEARCH GROUP**

SWIR Photodiode and tunable laser based on micro-transfer printing



Candidate: Xin Guo

Supervisors: Prof. Gunther Roelkens & Dr. Sarah Uvin

10th October, 2025

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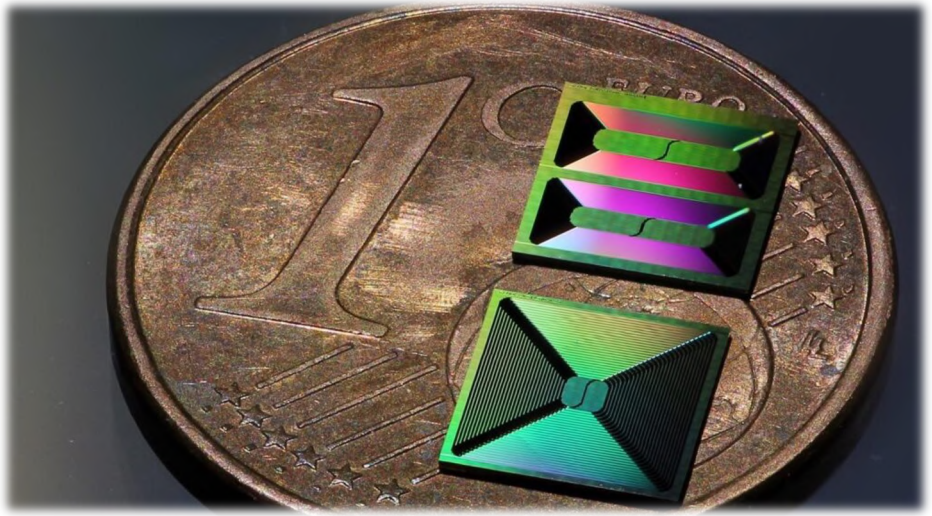
Wave, light and photonic chips

What, why and how, an introduction



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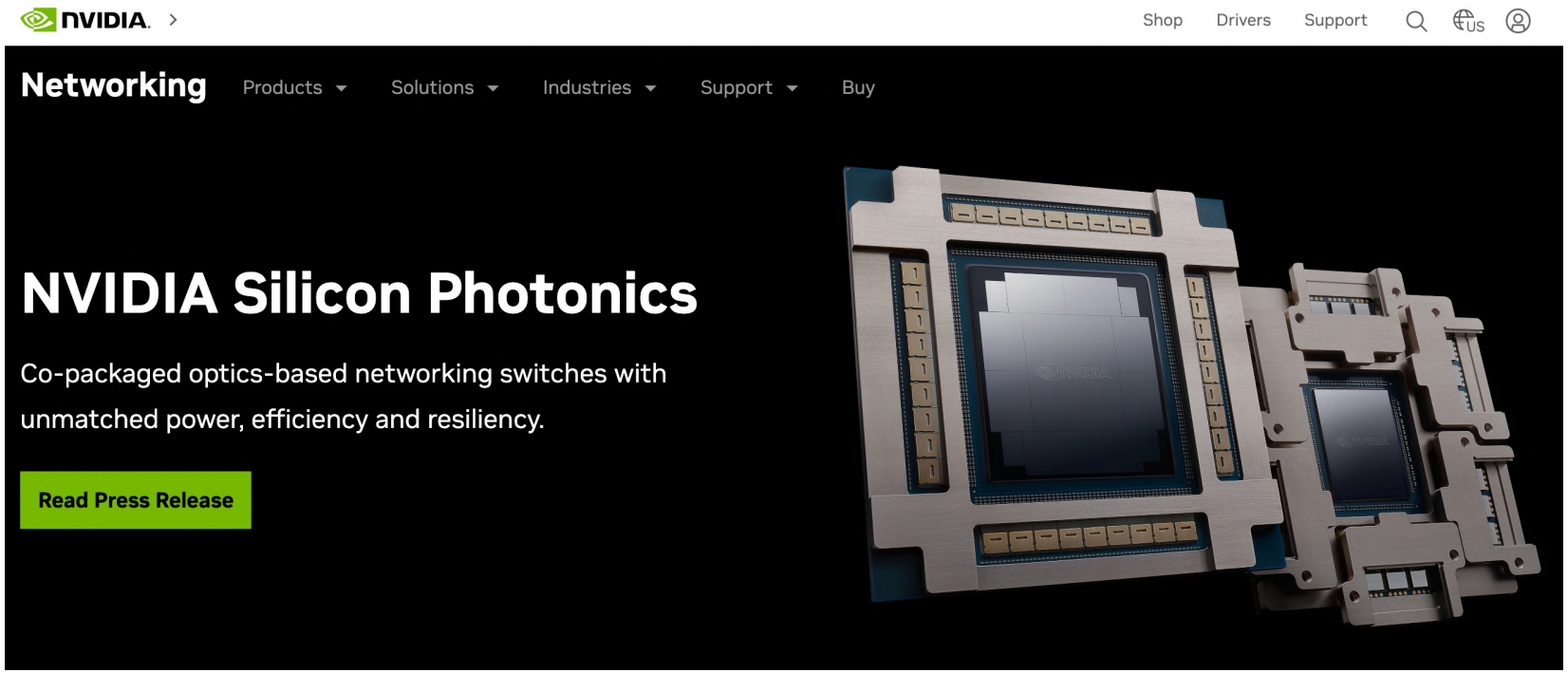
Self-driving tech: do you trust it?

Self-driving → Optical Sensors

NVIDIA steps into Photonics



- Production-ready & co-packaged
- Next-gen networking
- Lower energy consumption

Europe's first dedicated photonics fab

Stel je vraag

vrt nws

Binnenland Economie

Oudenaarde krijgt nieuwe chipfabriek, goed voor 500 jobs: "Europa's eerste centrum voor fotonische chips"

© imec

https://www.vrt.be/vrtnws/nl/2025/08/21/nieuwe-chipfabriek-in-oudenaarde/

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Light: More Than What We See

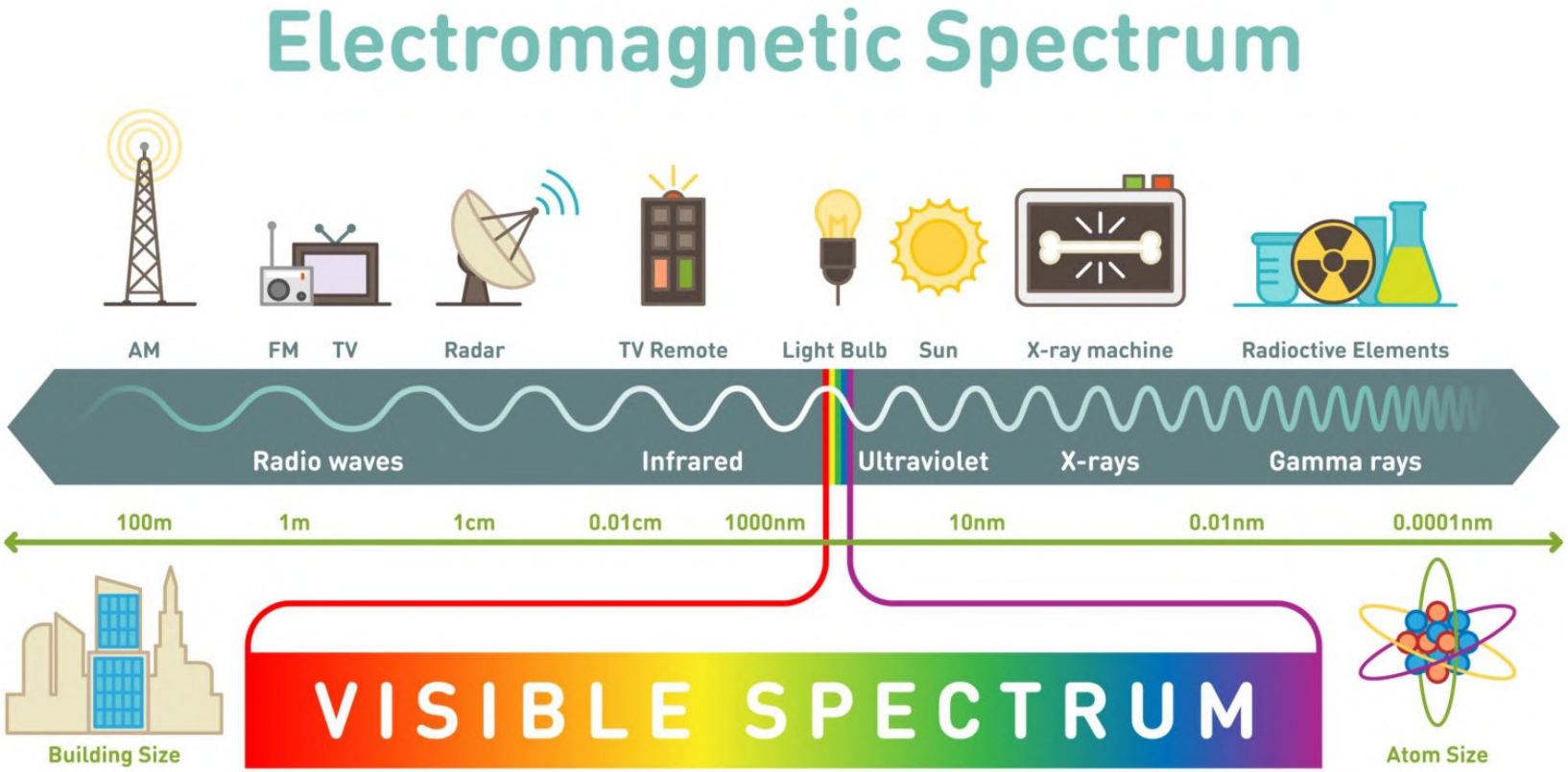
Light is energy that travels as a wave at different frequencies

Speed of light

$$f = \frac{c}{\lambda}$$

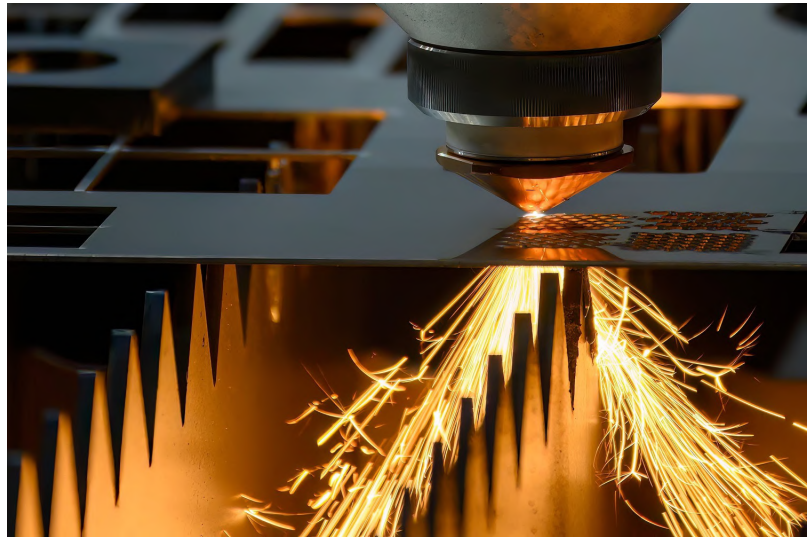
Frequency

Wavelength

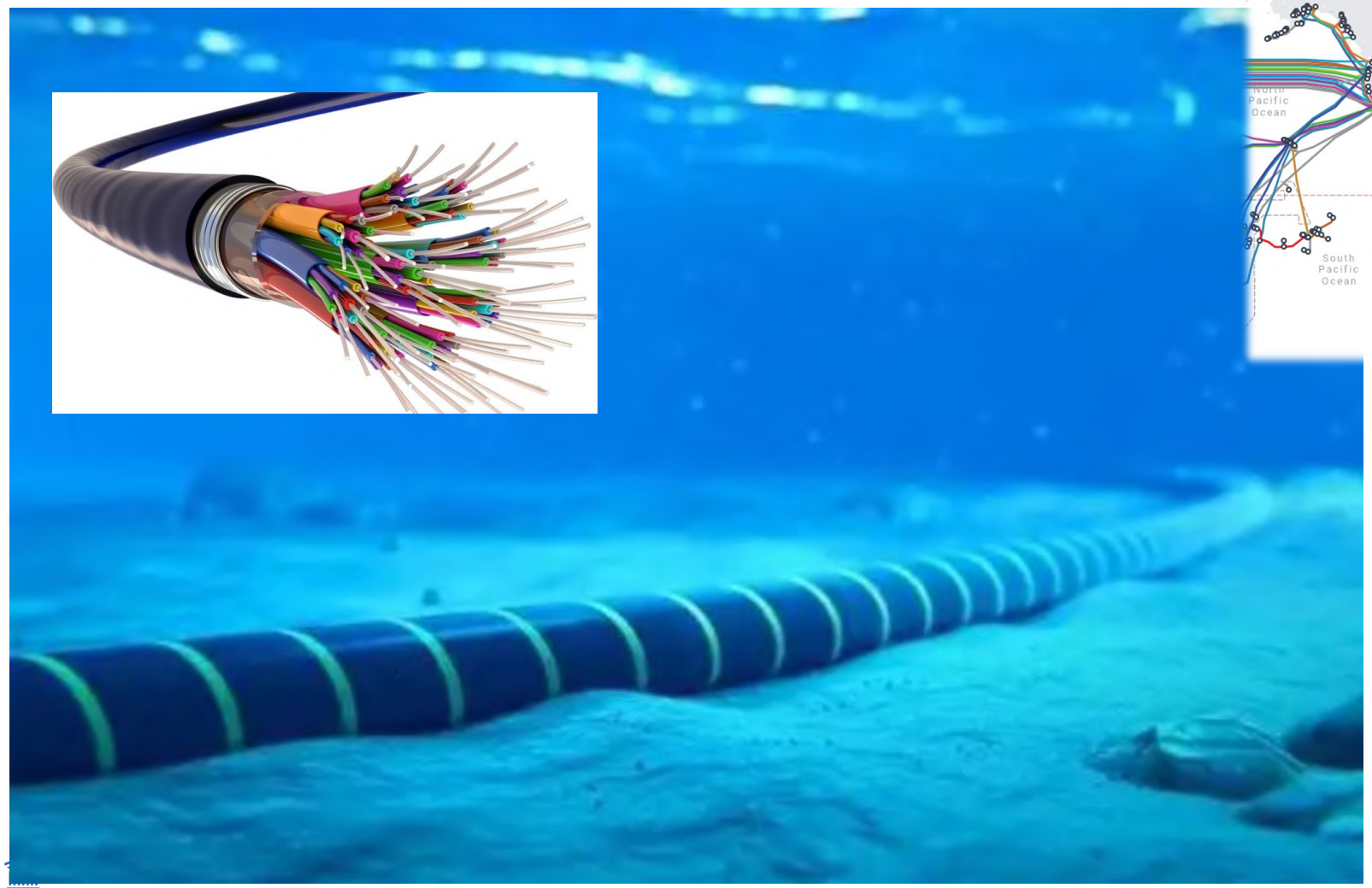


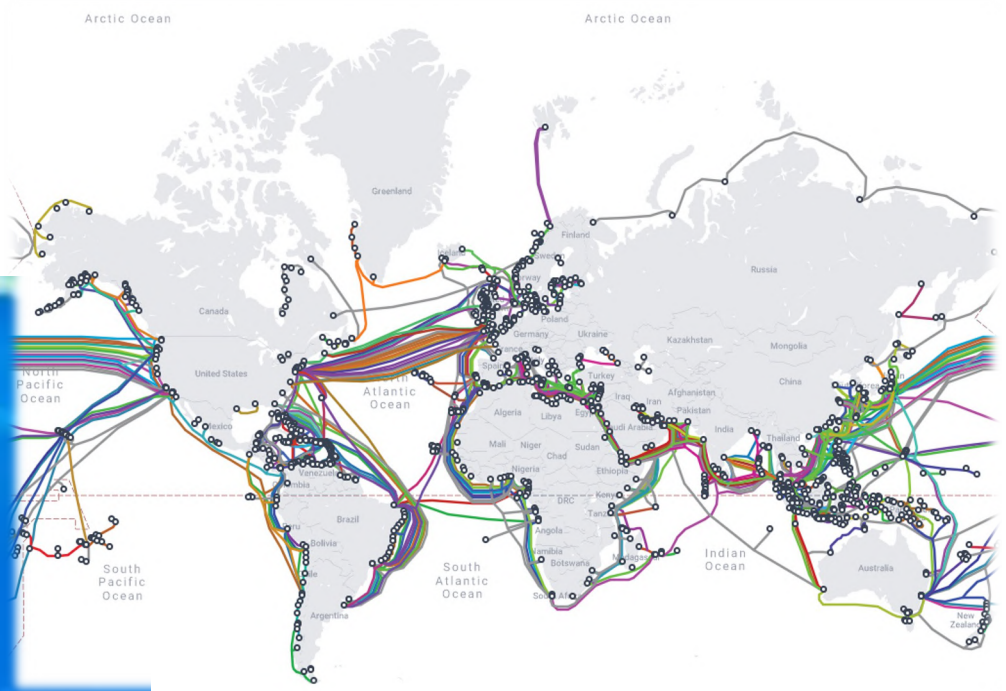
400 – 700 nm

Light carries energy



World is connected by fibers





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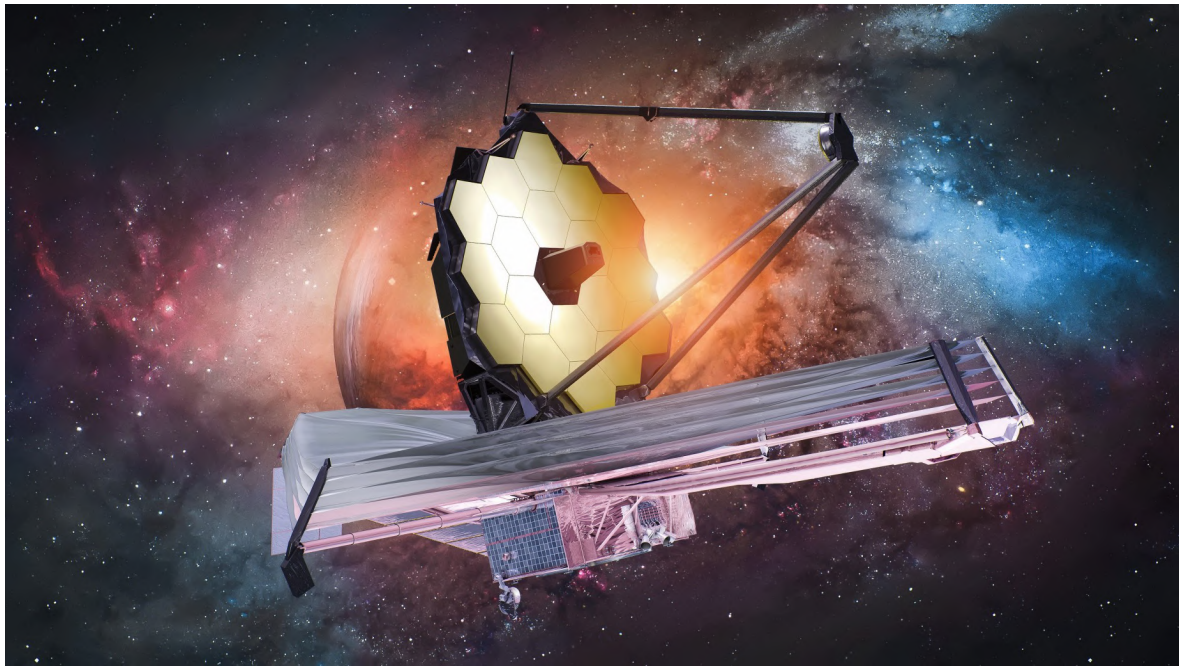
Light carries information



James Webb Space telescope

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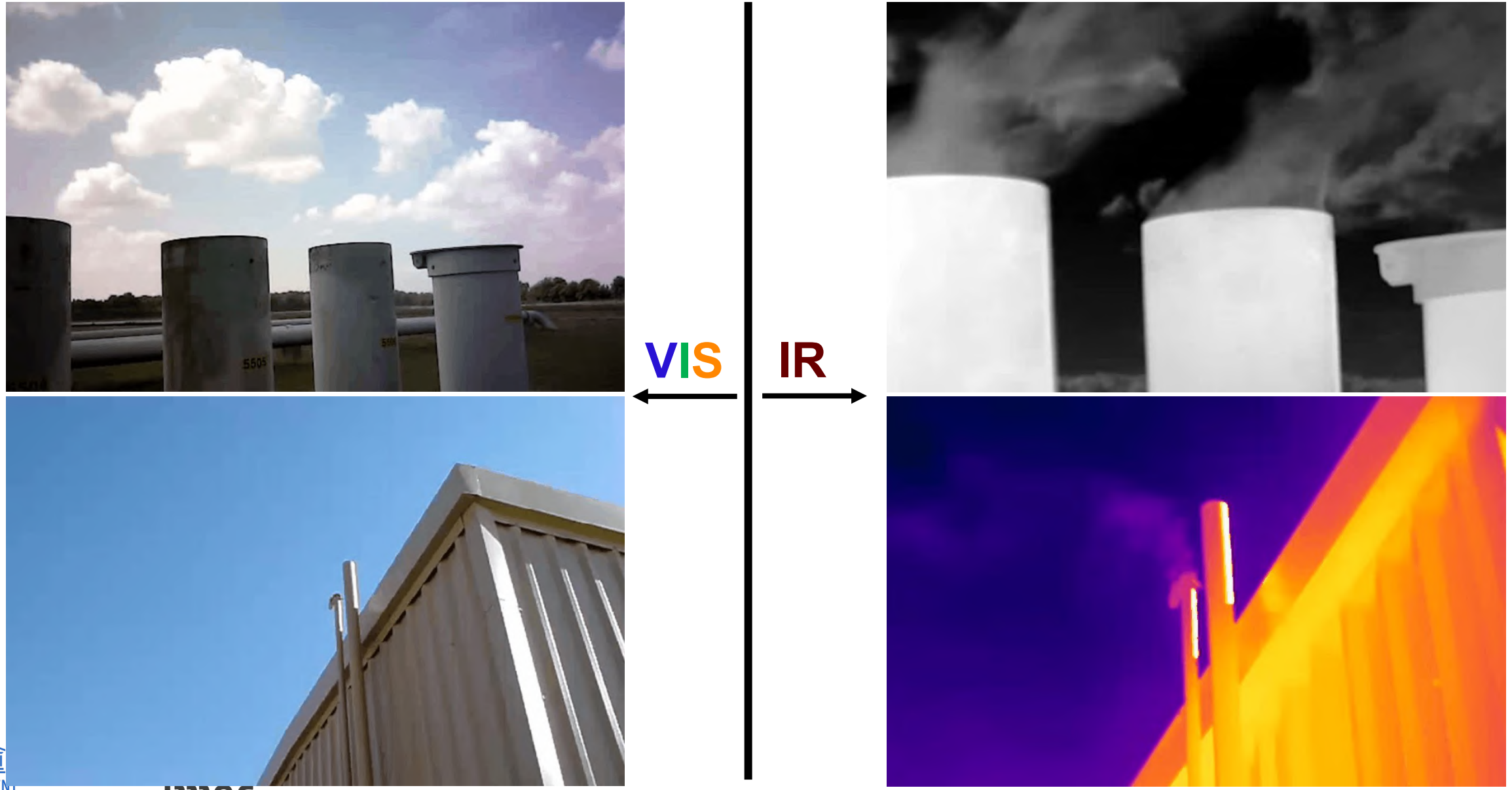
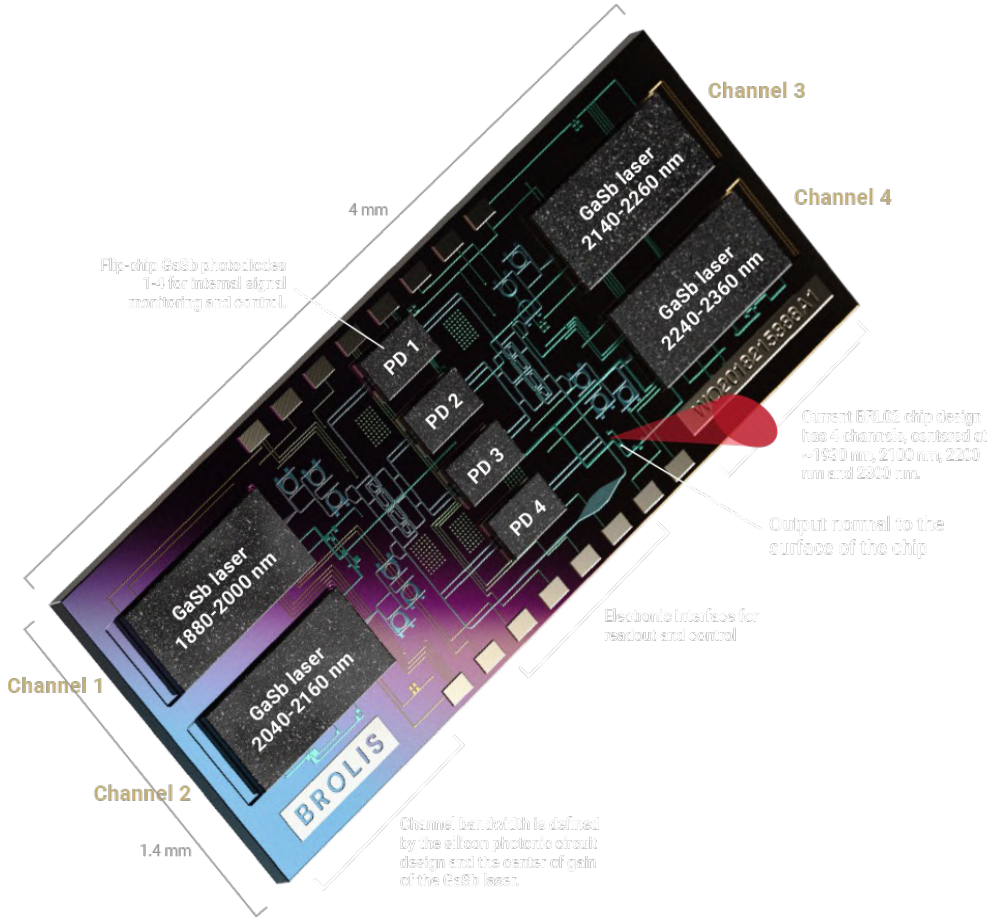
Optical detection



Source: Teledyne FLIR YouTube channel

In-line milk analyzer



https://brolis-sensor.com/

The **BROLIS HerdLine** milk analyzer monitors

Benefits – a productive advantage

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CHIPS: what?

How many chips are shown in this picture?

There are 50-150 individual semiconductor chips in a smartphone

CHIPS: where can we find them?

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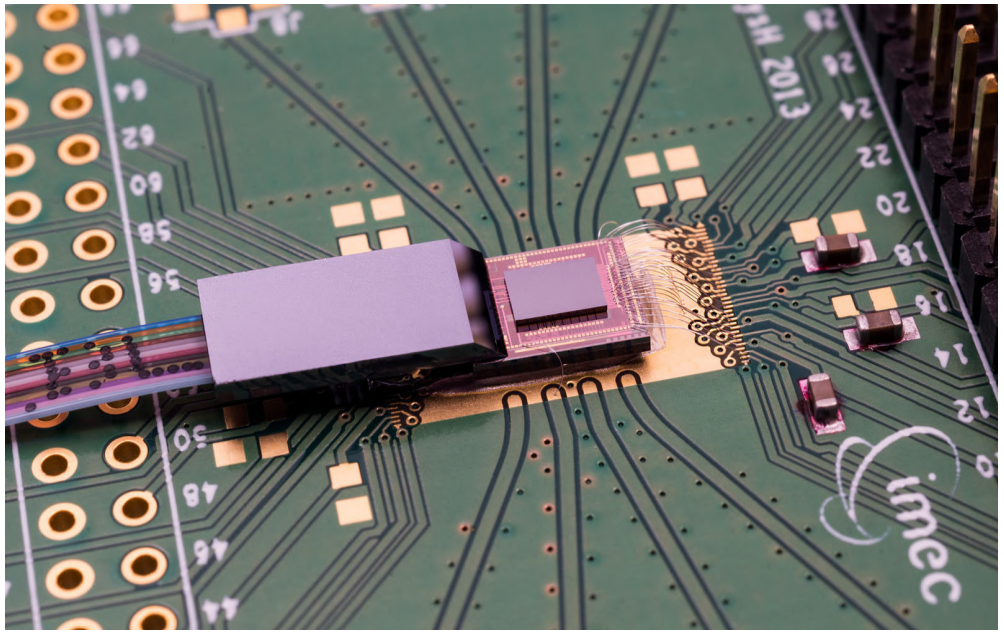
Bulky optical system vs PIC (fotonische geïntegreerde schakelingen)

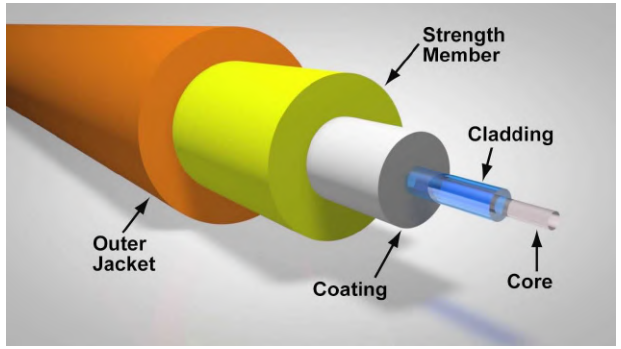
Free-space optical system

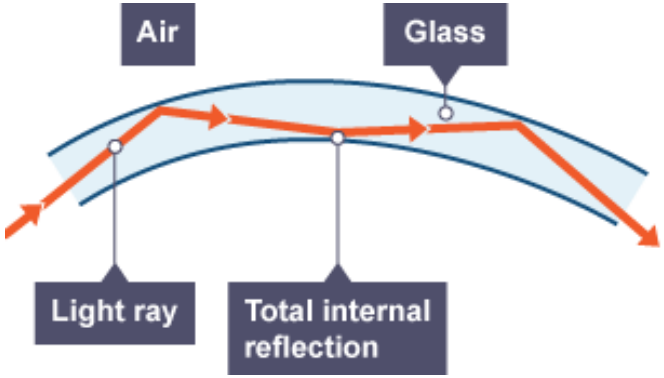


Photonic chips (PIC)

Waveguides are microversion of optical fibers

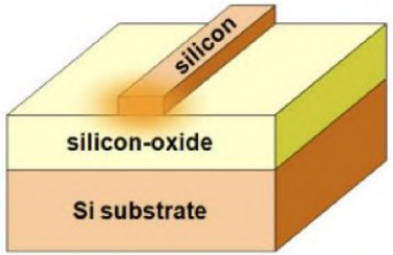
Fibers:

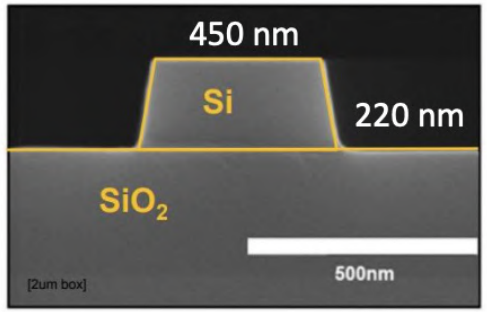


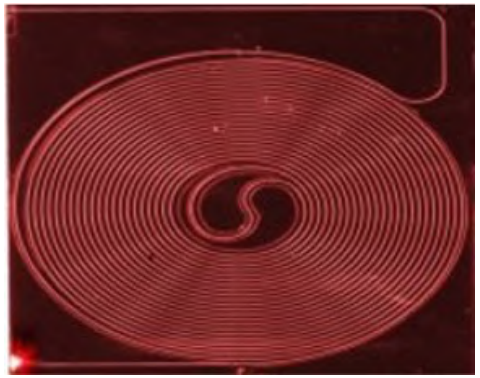


- Light can be guided by materials with a higher refractive index than their surroundings
- Higher index contrast leads to stronger confinement and more compact circuits

Waveguides: (golfgeleider)



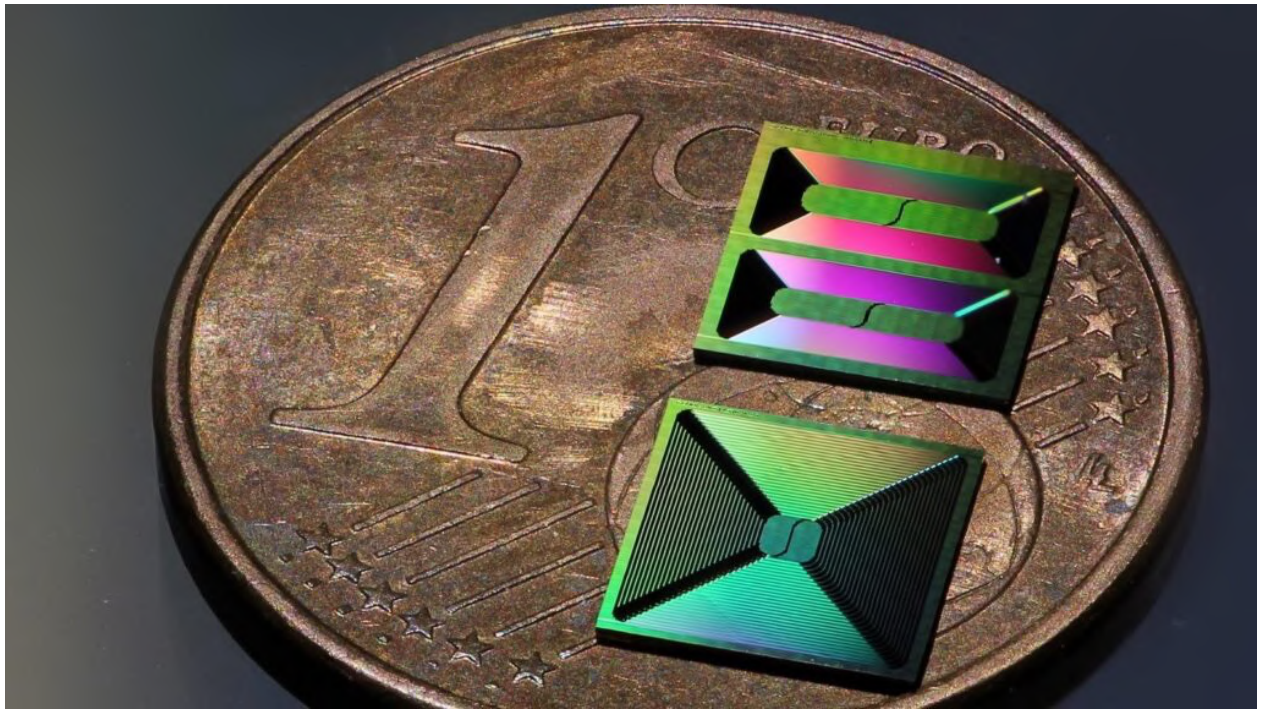




Source: PhotonHUB

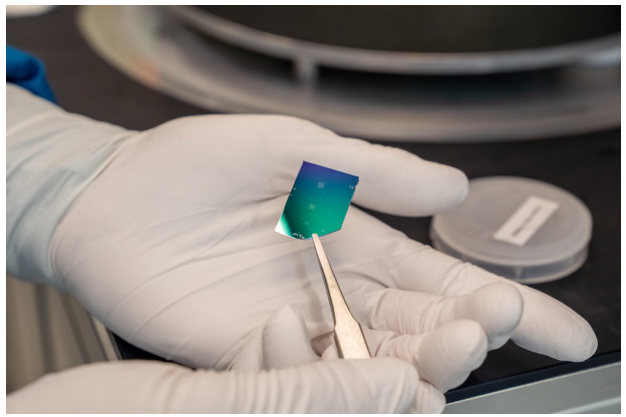
Waveguides are microversion of optical fibers

Proximus fiber termination box



PIC with 1 meter long waveguide

How do we make photonic chips



Source: Medialibrary PRG

We use BIG and EXPENSIVE tools to make TINY chips

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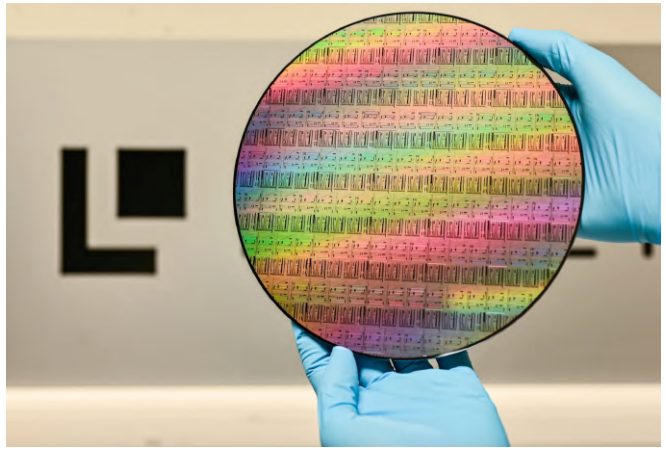
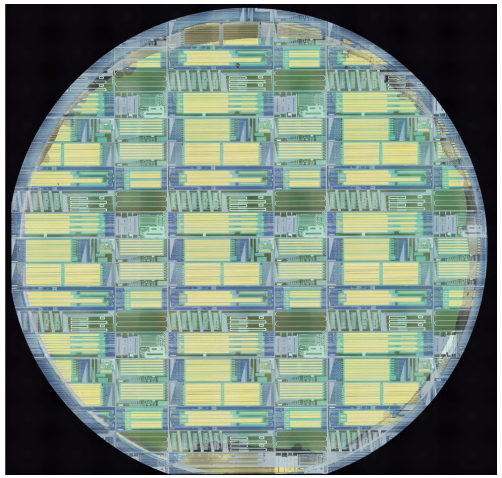
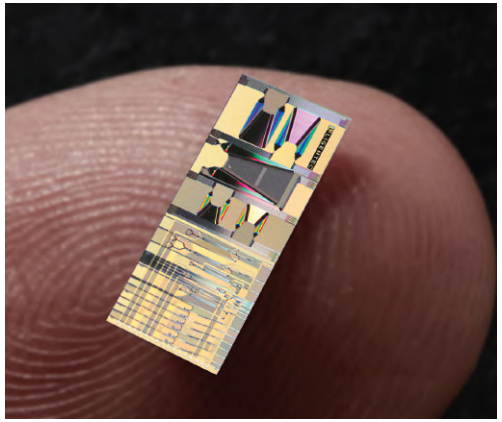
How do we make photonic chips

Blank wafer



Processed wafer





Source: Ligentec SA

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Application: datacenter

In a typical data center

- 1 million computers
- All connected via optical fiber

$\Rightarrow$ Requires numerous transceivers to do the convention from electrical to optical signals.

Omzetter ('transceiver')

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Application: Lidar

A lot of people do it...

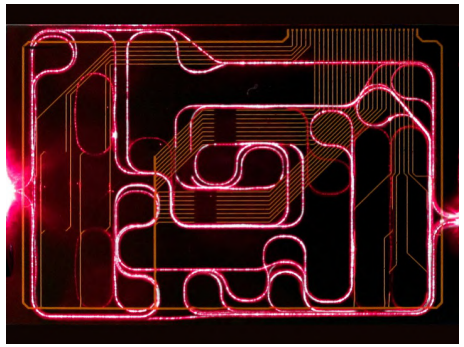
Lidar enhanced sensor on the car

Take home messages:

- Light is a wave with energy and information
- Photonic chips (PIC) = miniaturized optical systems
- PICs enable compact, scalable, and versatile technologies.

Active Components in PICs

Laser



PIC

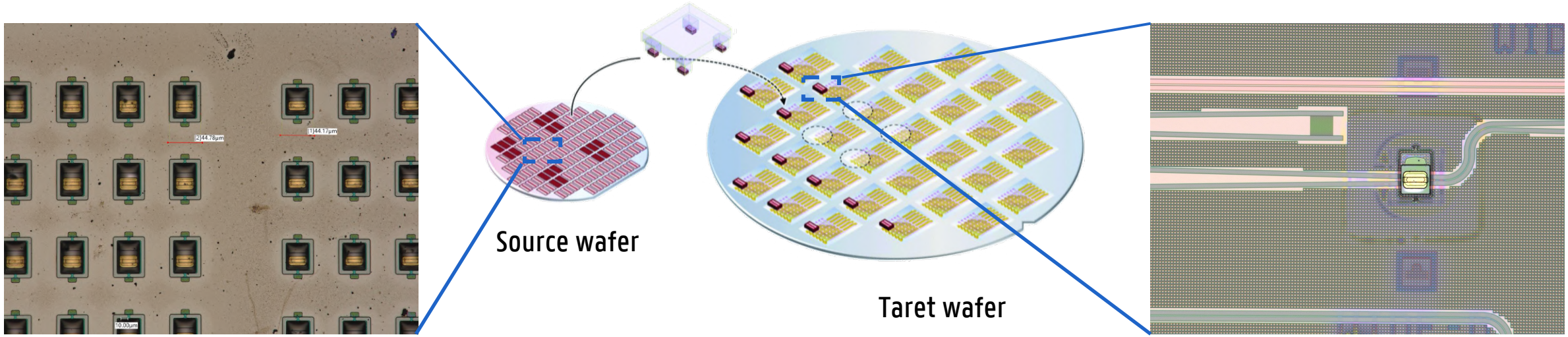
Photodiode

- Laser → generates light (electrical → optical)
- Photodiode → detects light (optical → electrical)

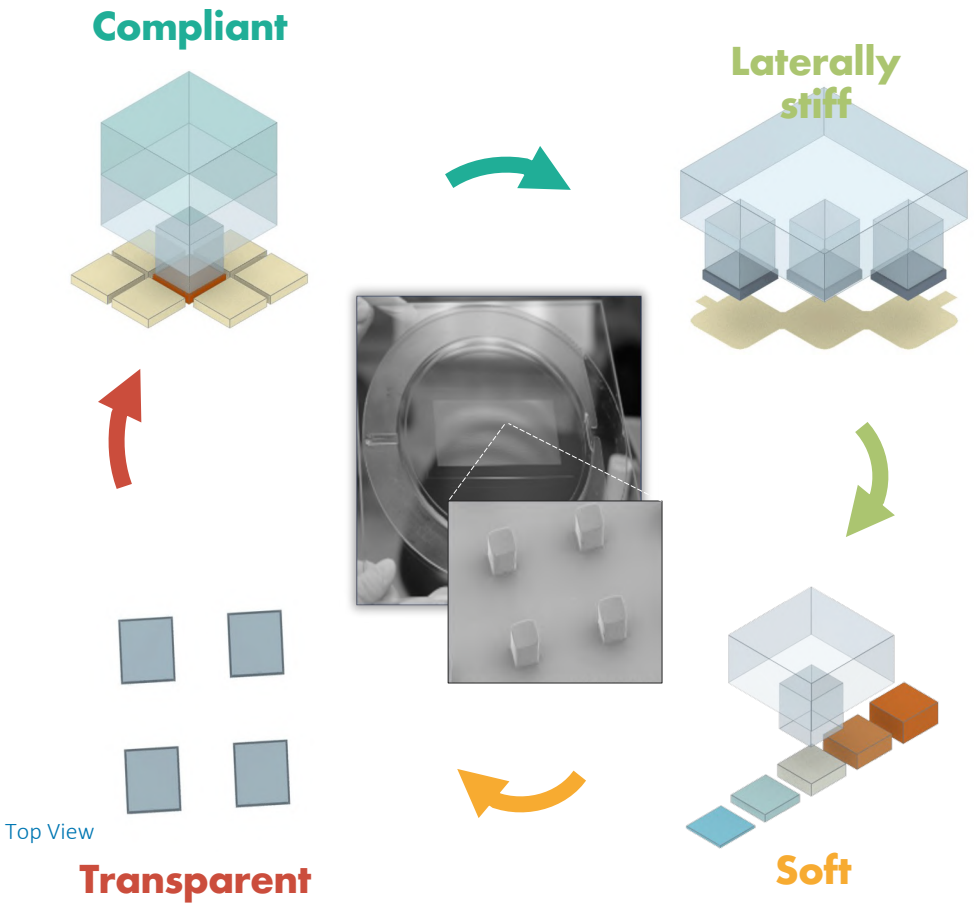
How can we do better?
Put laser & Photodiode on-chip!

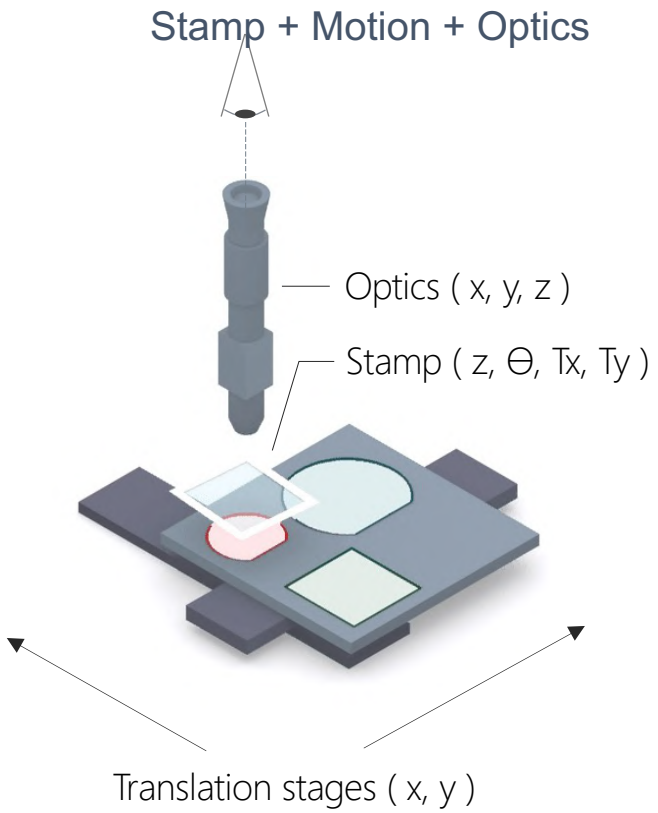
Heterogeneous integration

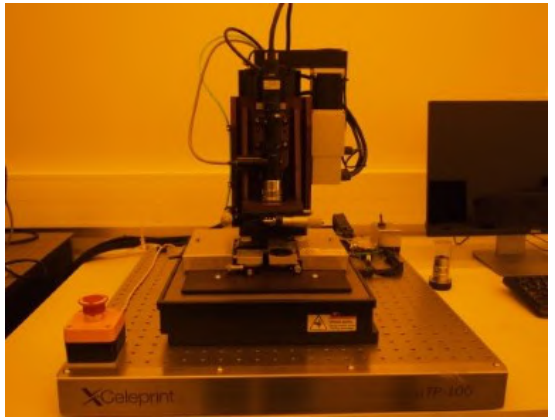
- **Micro transfer-printing**

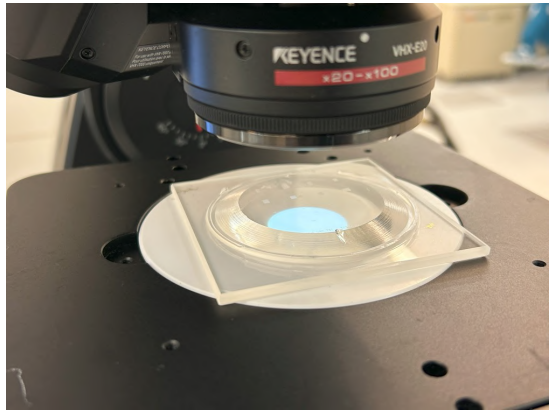


Miro-transfer printing

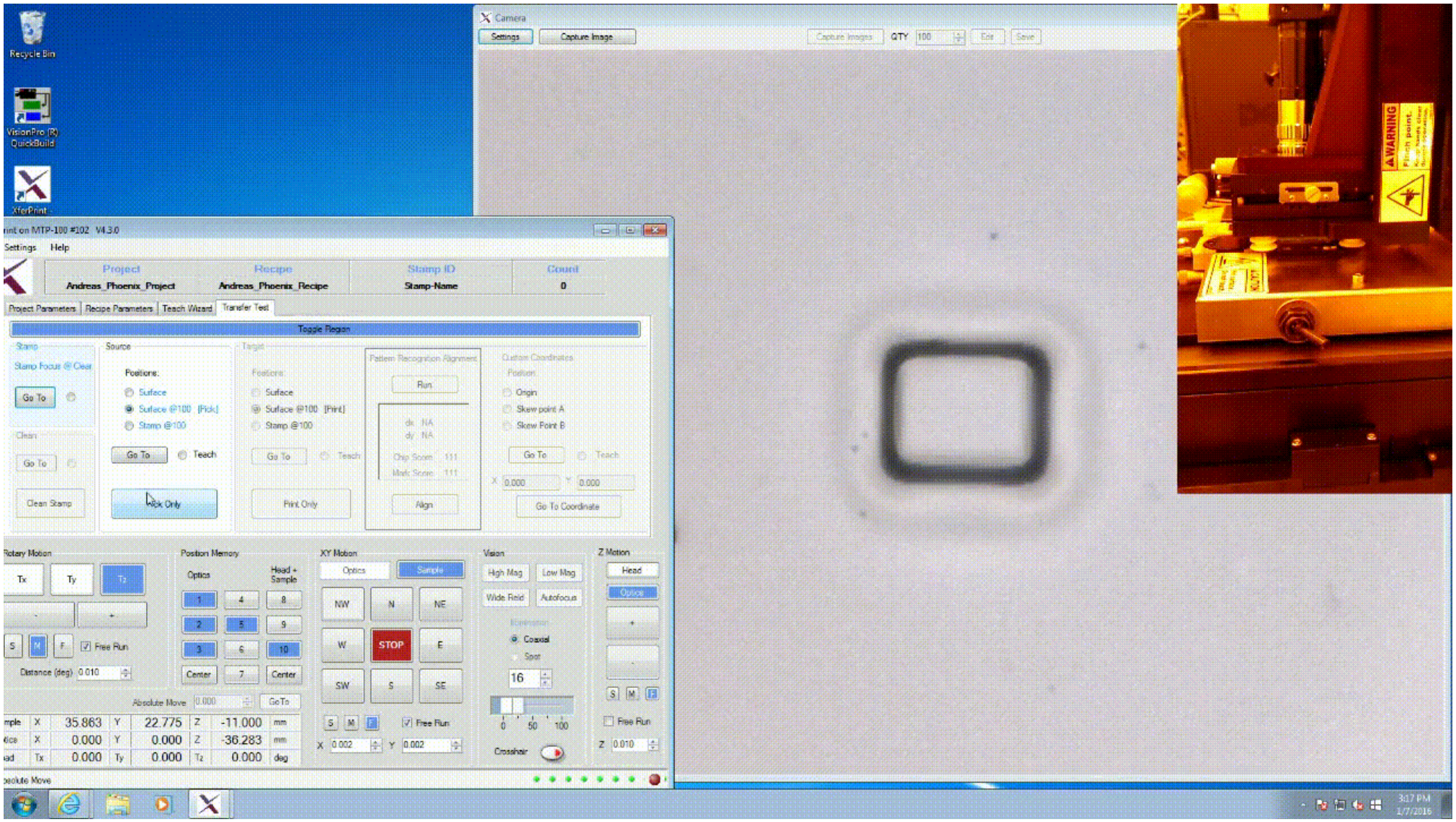






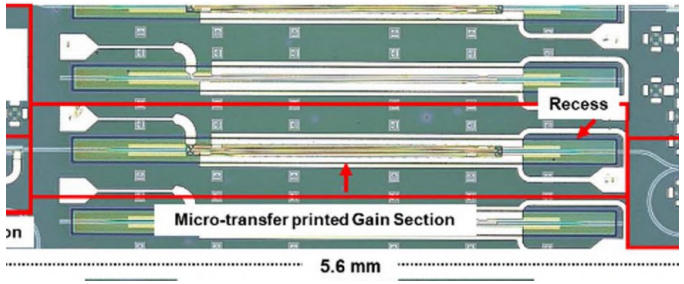


Miro-transfer printing

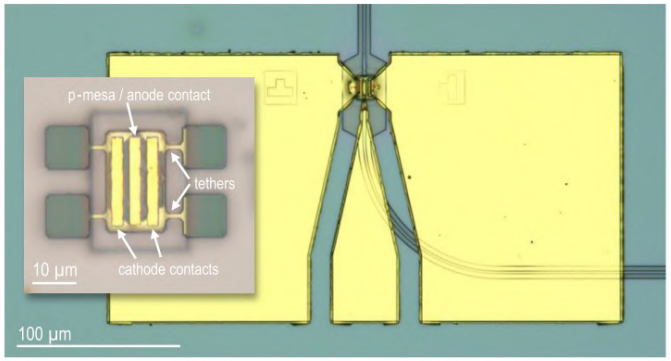


Heterogeneous integration

Laser and Photodiode at C-band

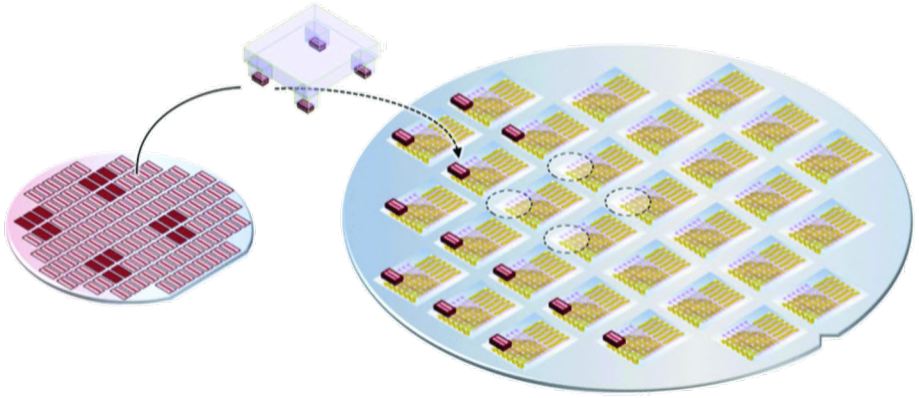


B. Pan et al. *Photonics Research* 12.11 (2024)

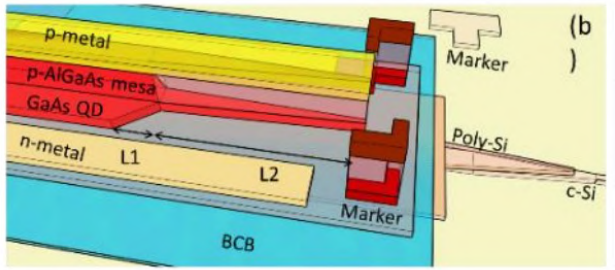


D. Maes et al. *APL Photonics* 8.1 (2023)

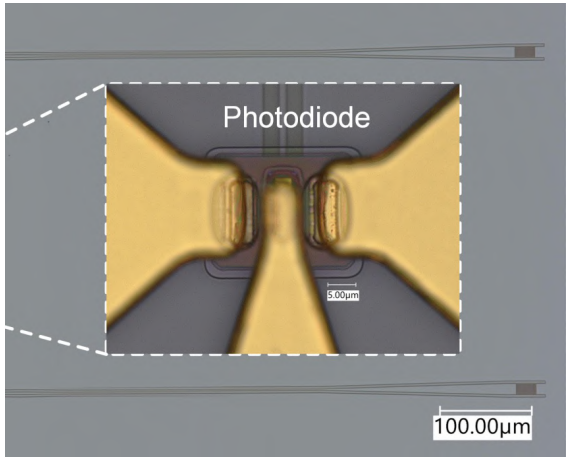
- **Micro transfer-printing**



Laser and Photodiode at O-band



J. Zhang et al. *ECIO, Netherlands* (2023)

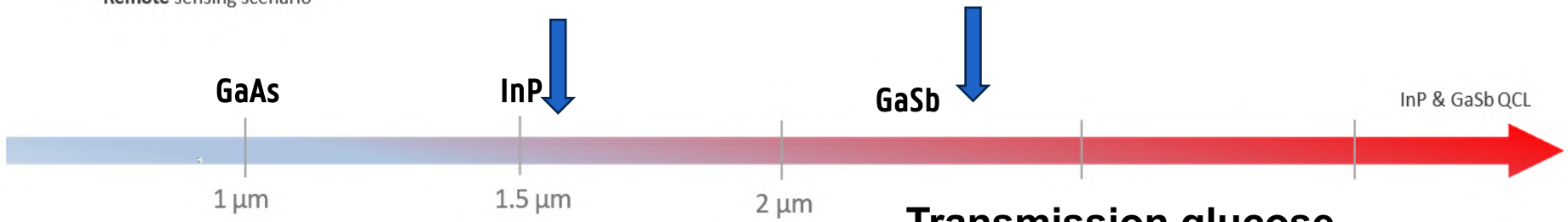


S. Qin et al. *Optics Express* 33.16 (2025)

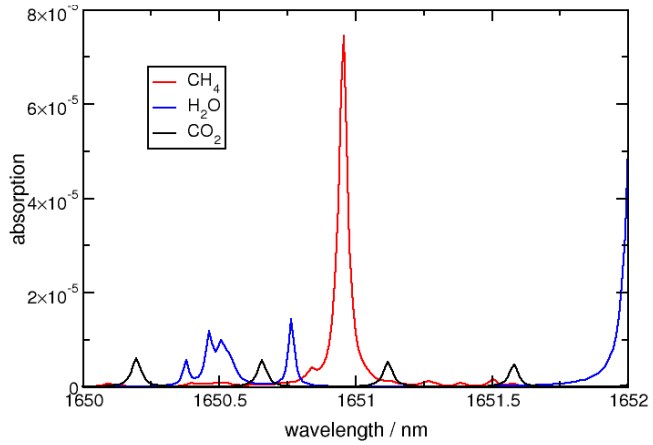
Beyond telecom waves - Short-wave infrared (SWIR)

Molecule-specific absorption of EM radiation

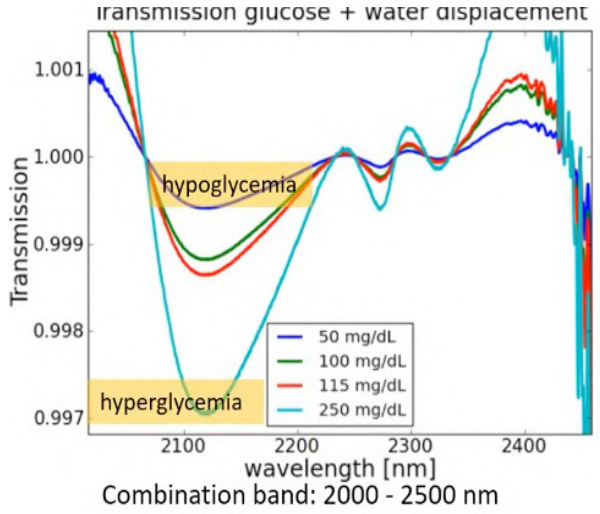
- **C-H**, **O-H**, **N-H**, **NH-OH**, **CH-CH** vibrations (stretch, bend, stretch+bend)
- **Direct** photon-phonon (molecule) interaction
- **Remote** sensing scenario



Transmission CH4 and CO2



Transmission glucose



Combination band: 2000 - 2500 nm

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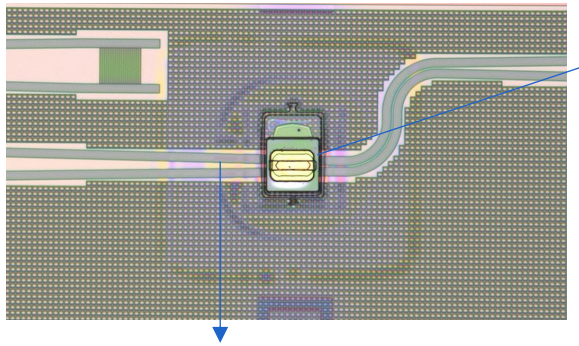
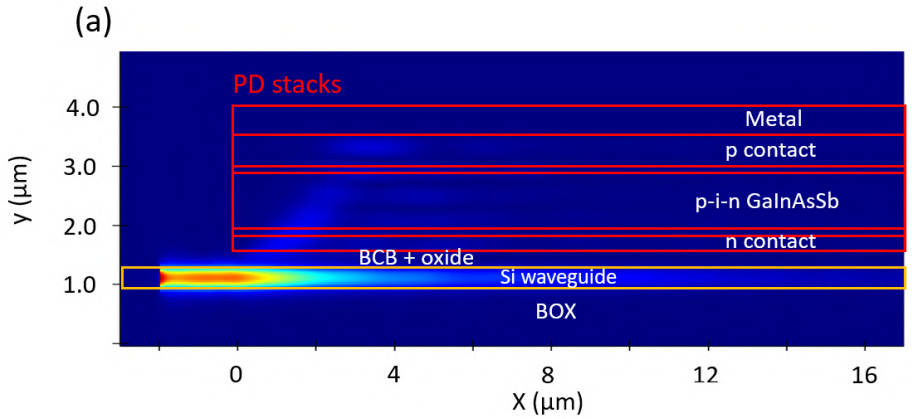
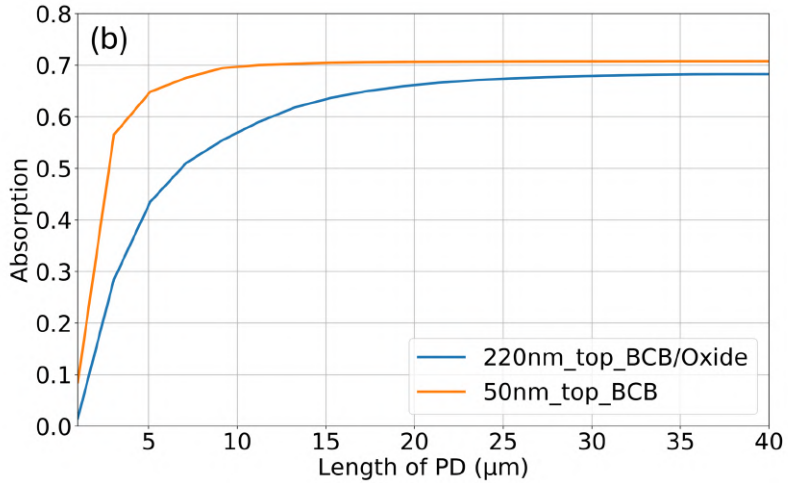
GaSb photodiode on SOI



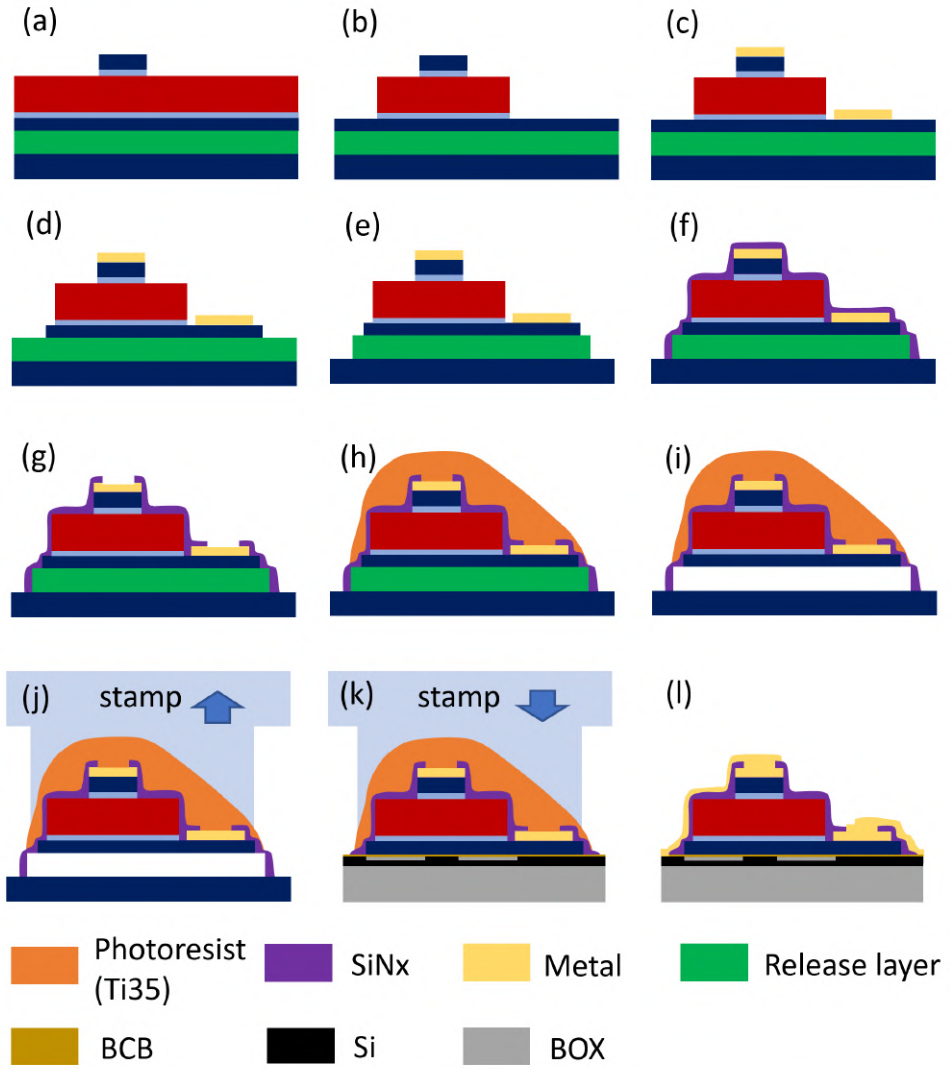


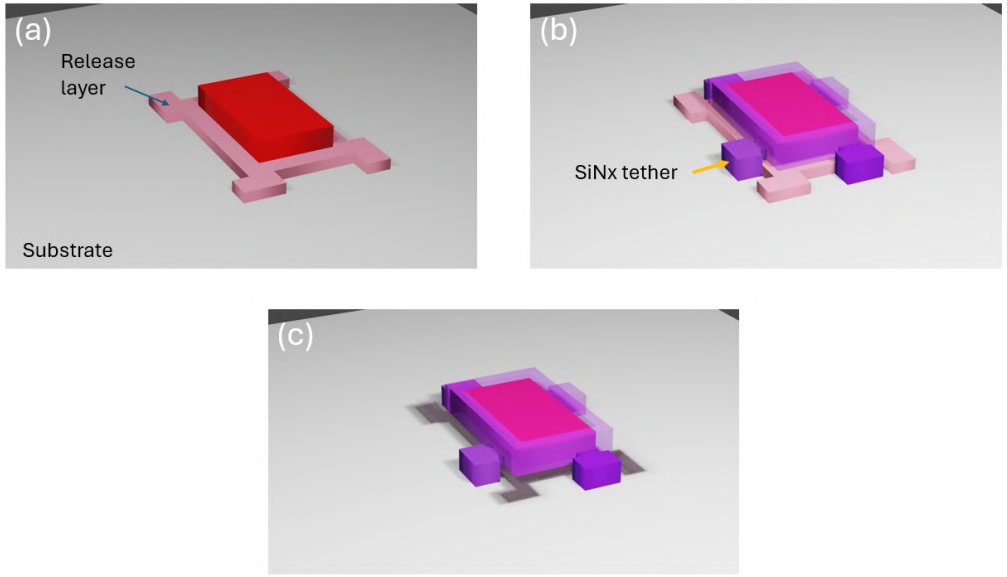
Light propagation in the evanescently coupled PD structure



Device absorption as function of length

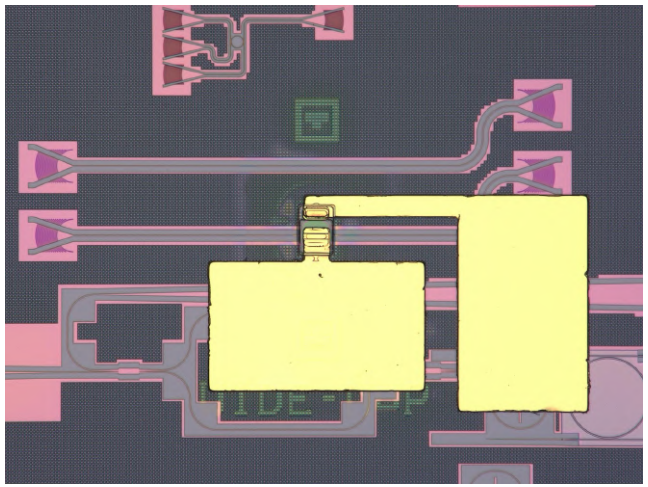
GaSb photodiode on SOI



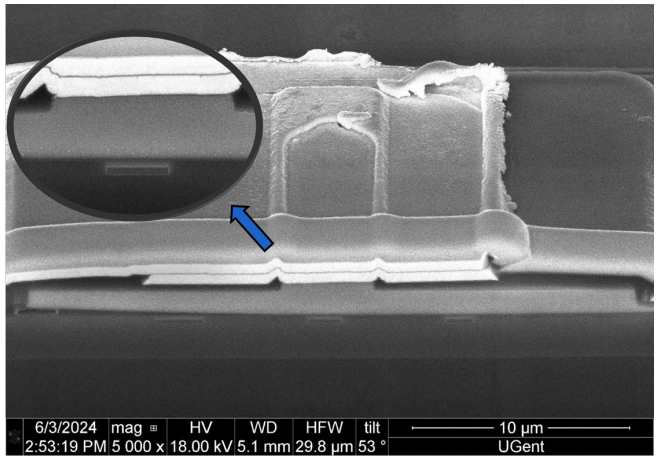


Processing for micro-transfer printing

GaSb photodiode on SOI

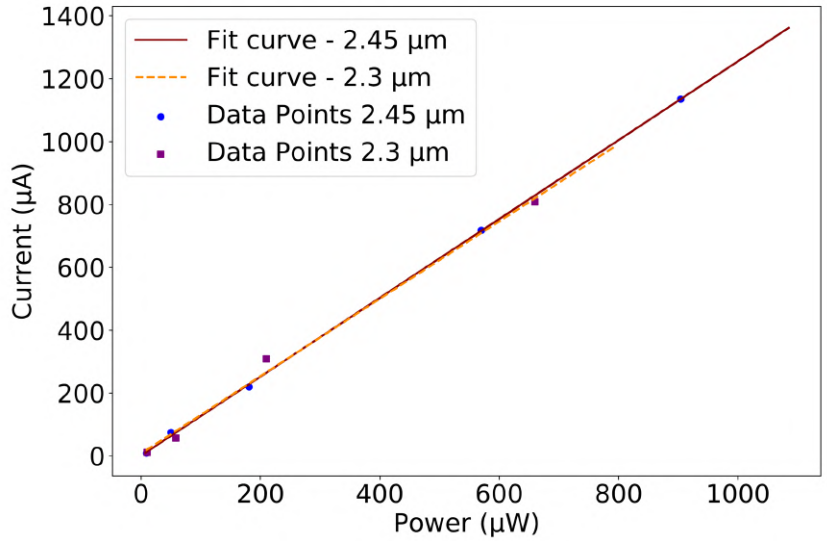


Photodiodes printed on PIC



FIB cross-section

Measurement result:



R = 1.23 A/W @ 2.3 um

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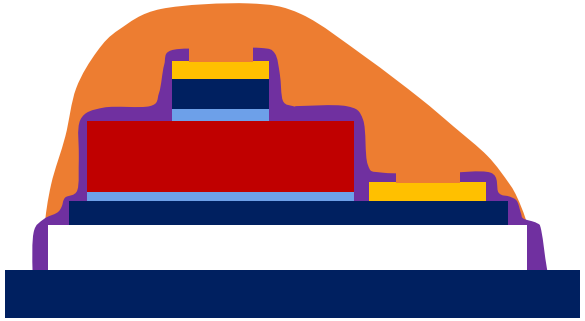
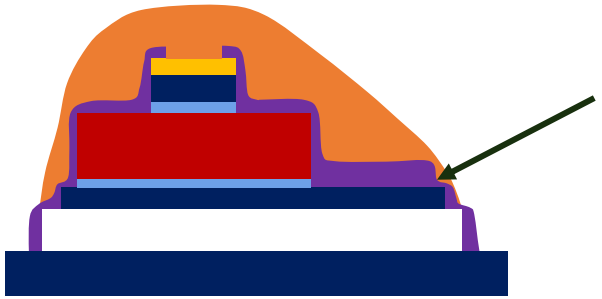
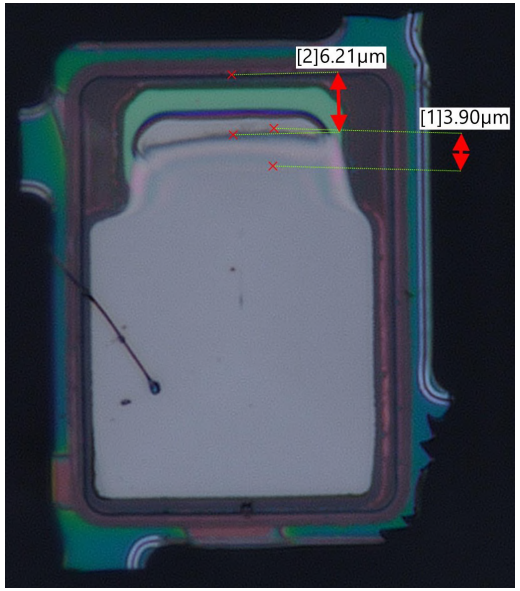
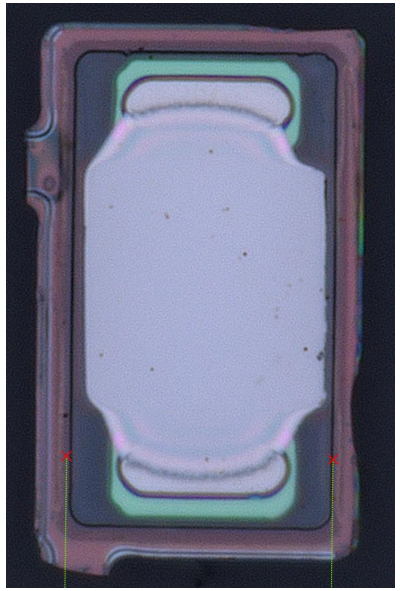
GaSb photodiode on SOI – backside uniformity



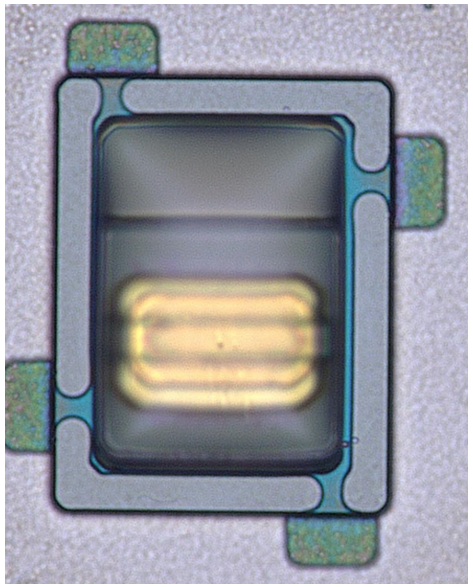


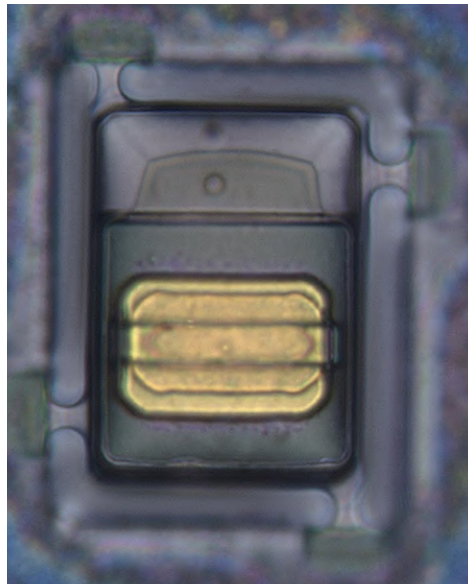




Coupon with one n contact

Coupon with two n contacts





Before release etch

After release etch

Coupons without n contact

Solution: Citric acid : H2O2 = 2:1 at 65˚C

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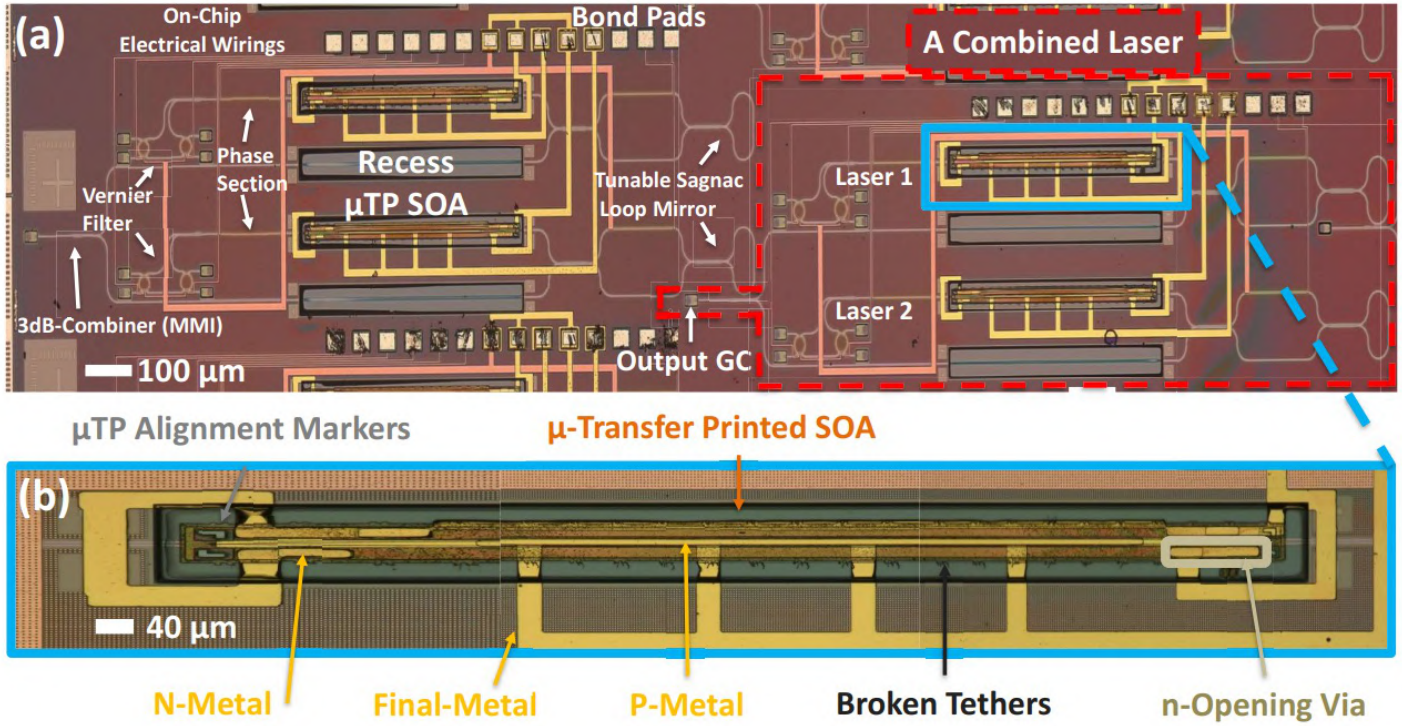
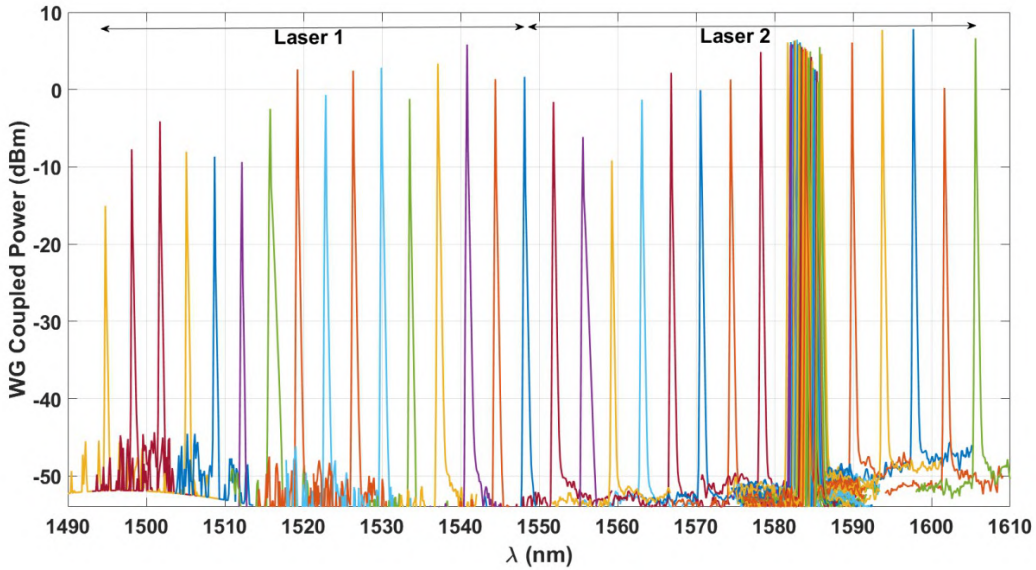
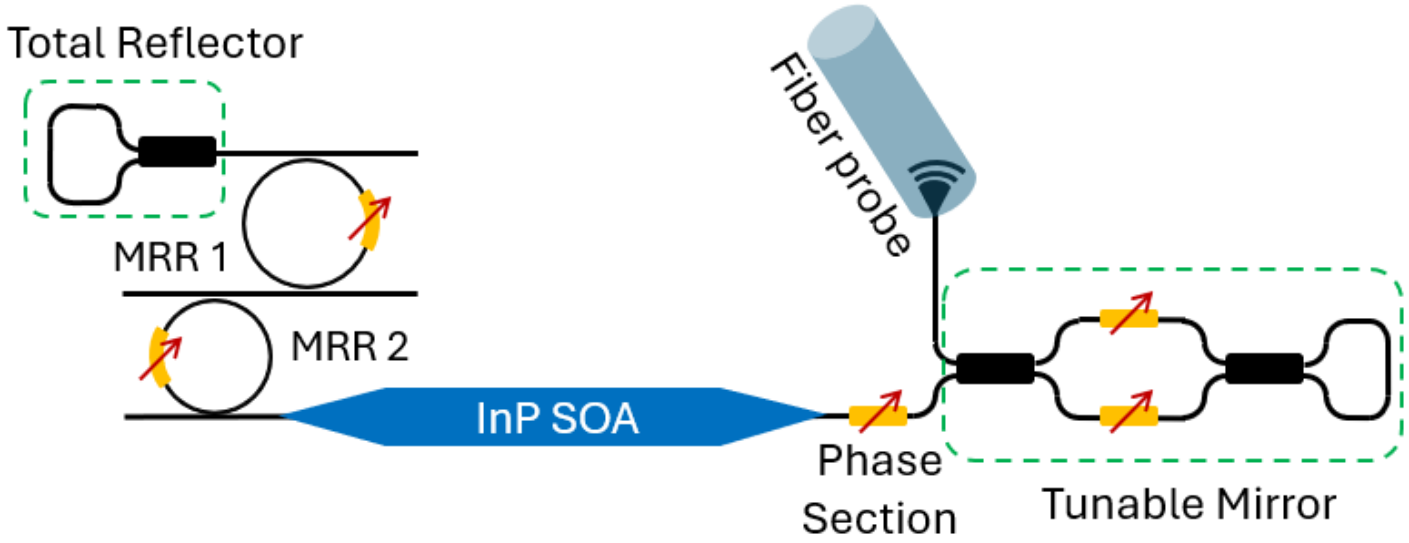
InP tunable laser at C-band





E. Soltanian et al. Optics Express 30.22 (2022)

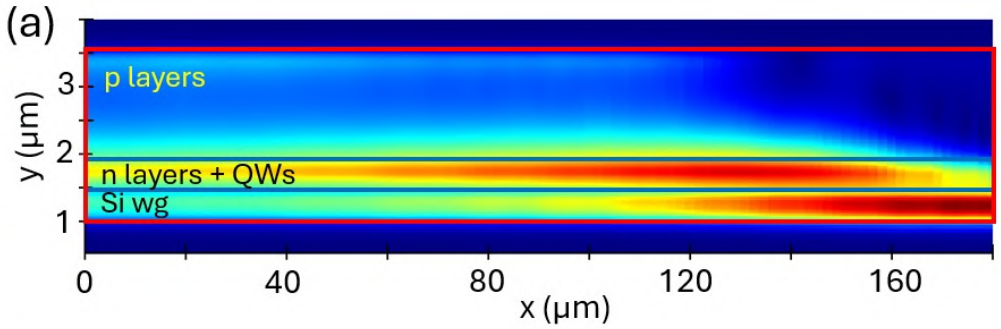
InP tunable laser at 1.67 µm

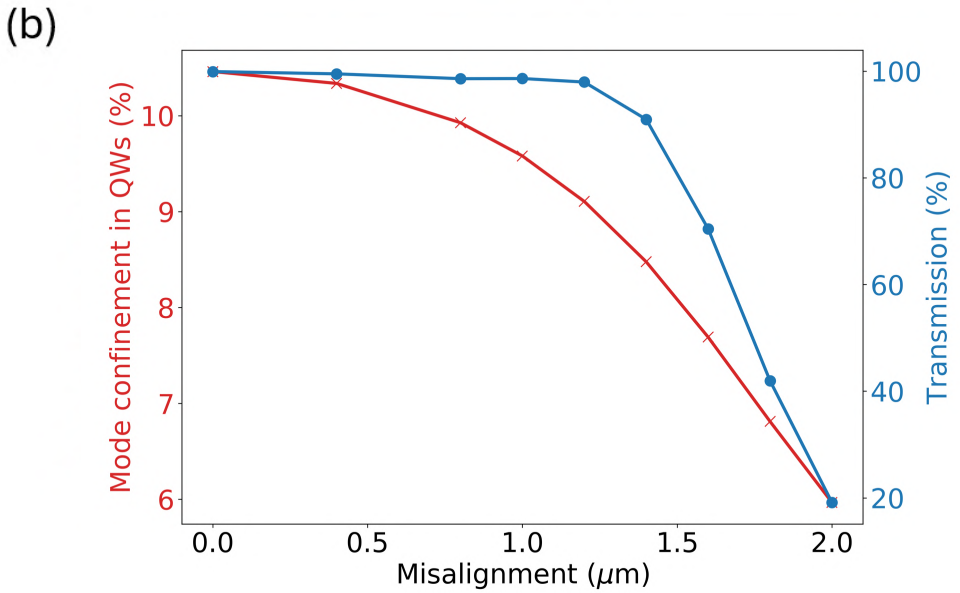


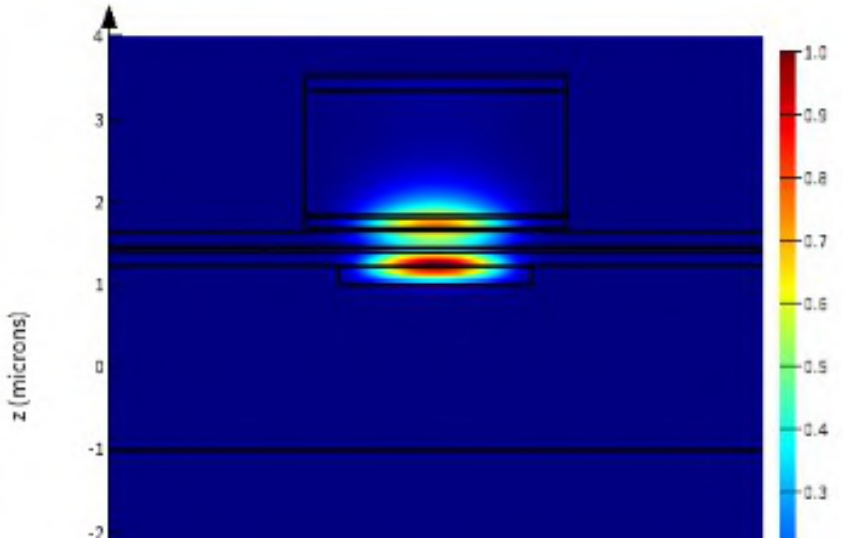
Moving to longer wavelength is not that straightforward:

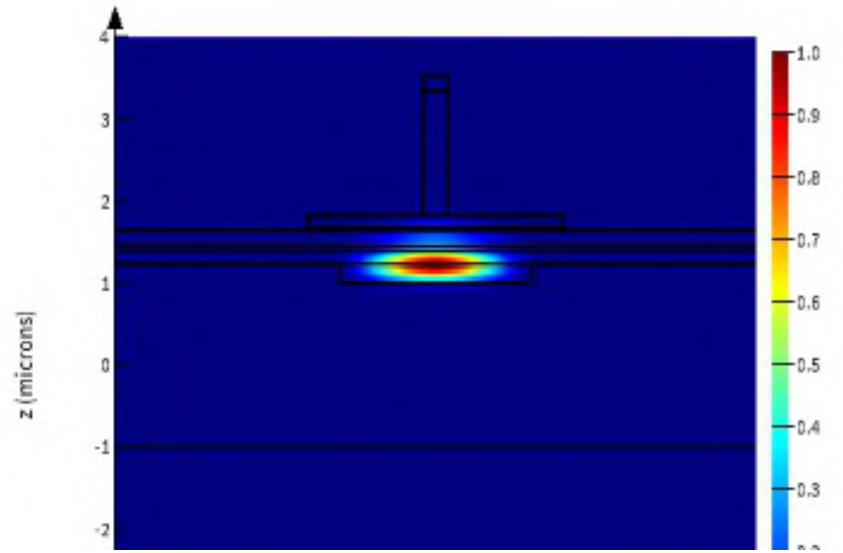
- Auger loss increases with wavelength
- Adjustments on SOI components and coupling

InP tunable laser at 1.67 µm









Lumerical simulation

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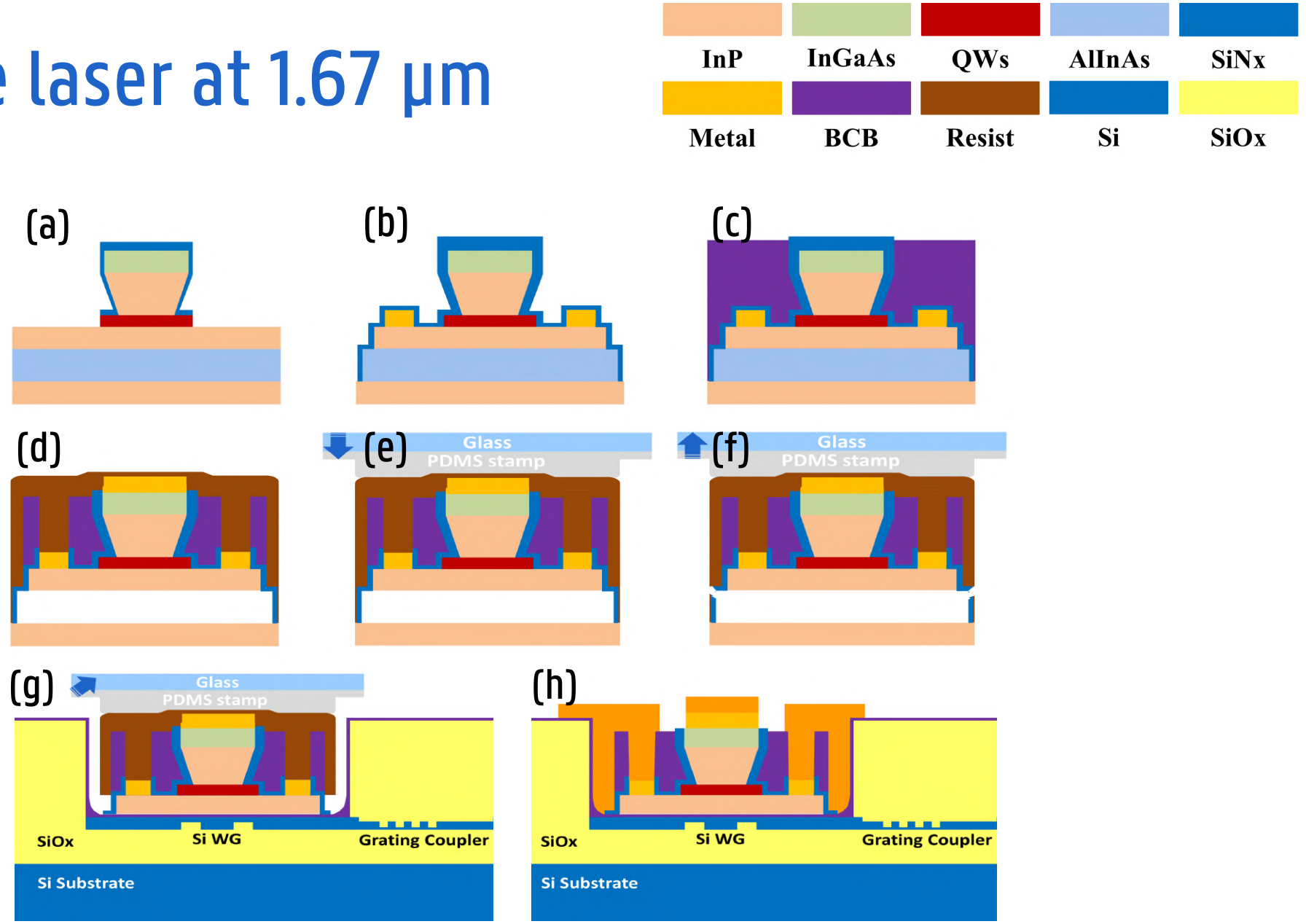
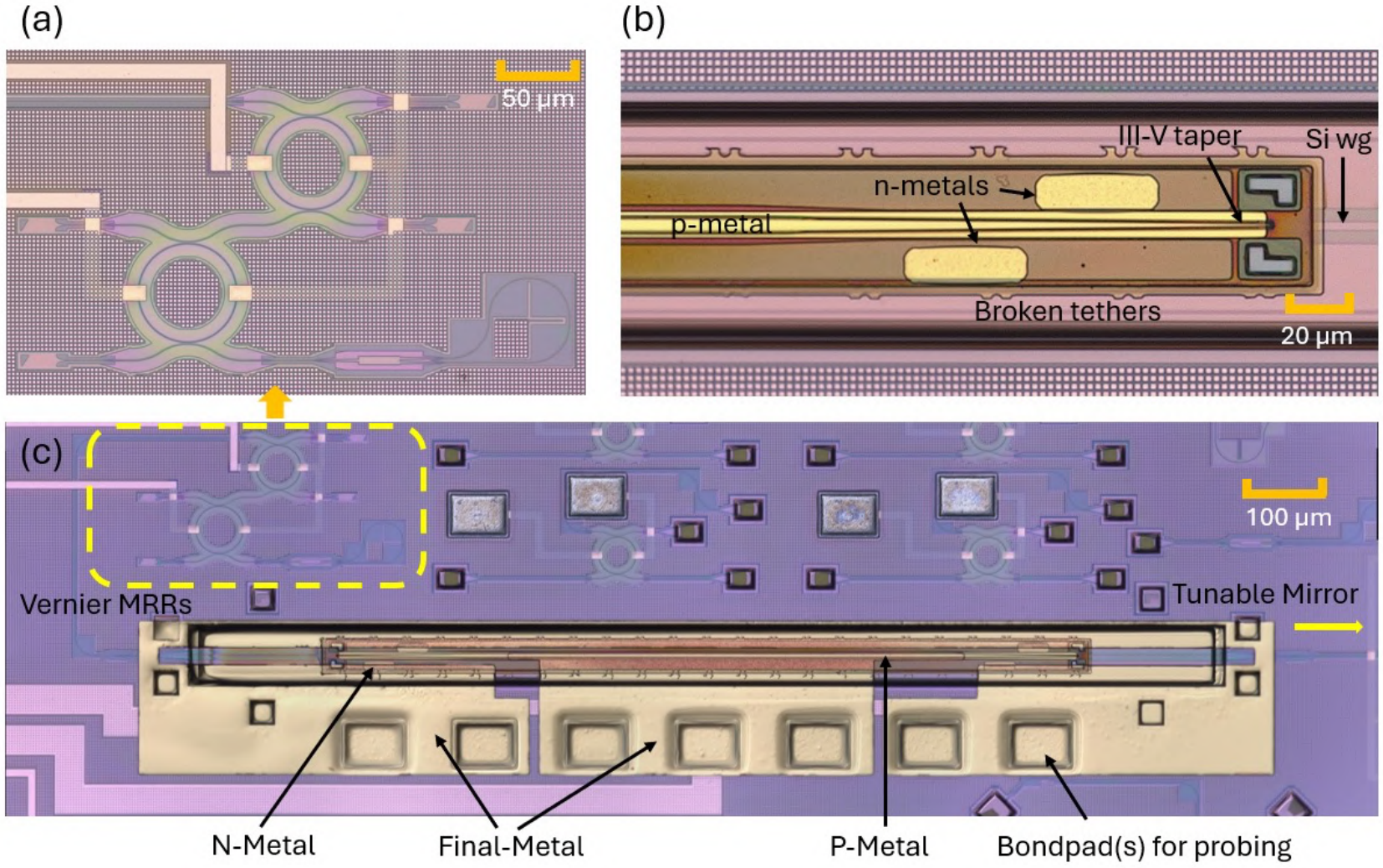
InP tunable laser at 1.67 µm

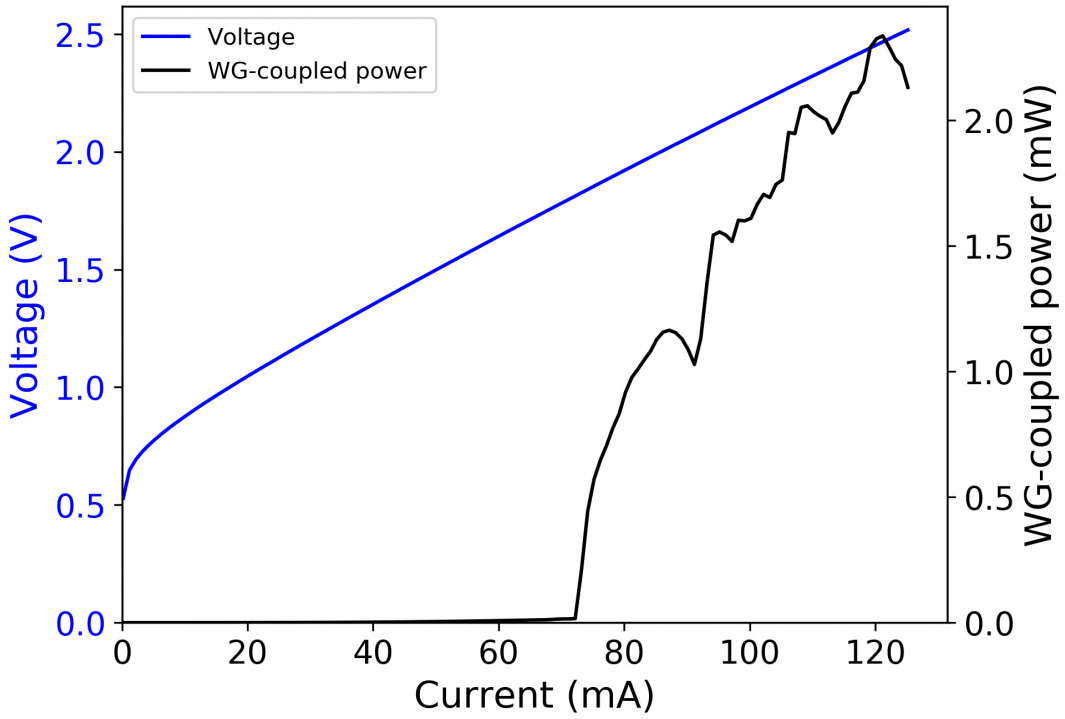


InP tunable laser at 1.67 µm

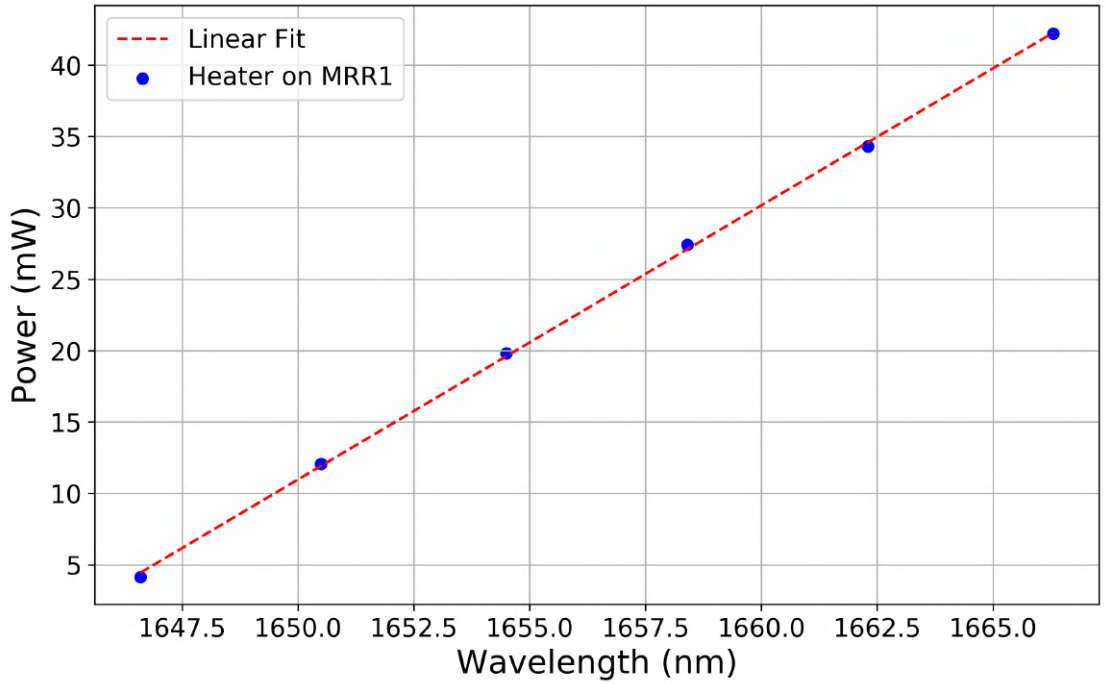


Microscope image of fabricated laser

InP tunable laser at 1.67 µm

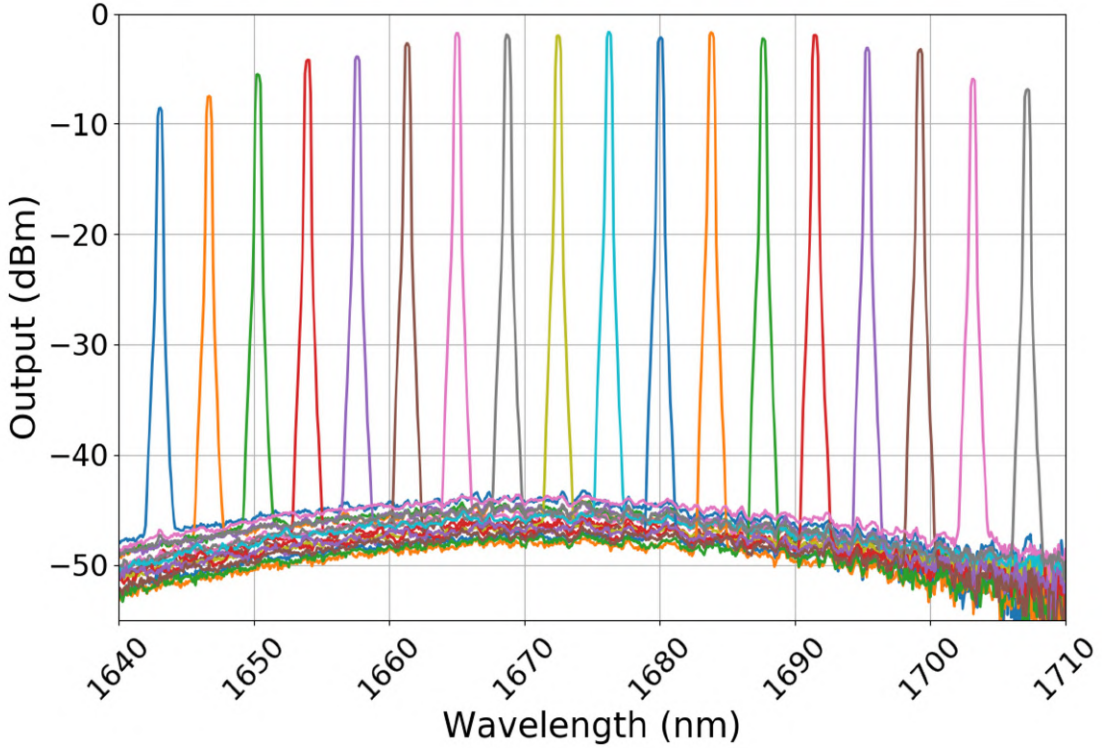


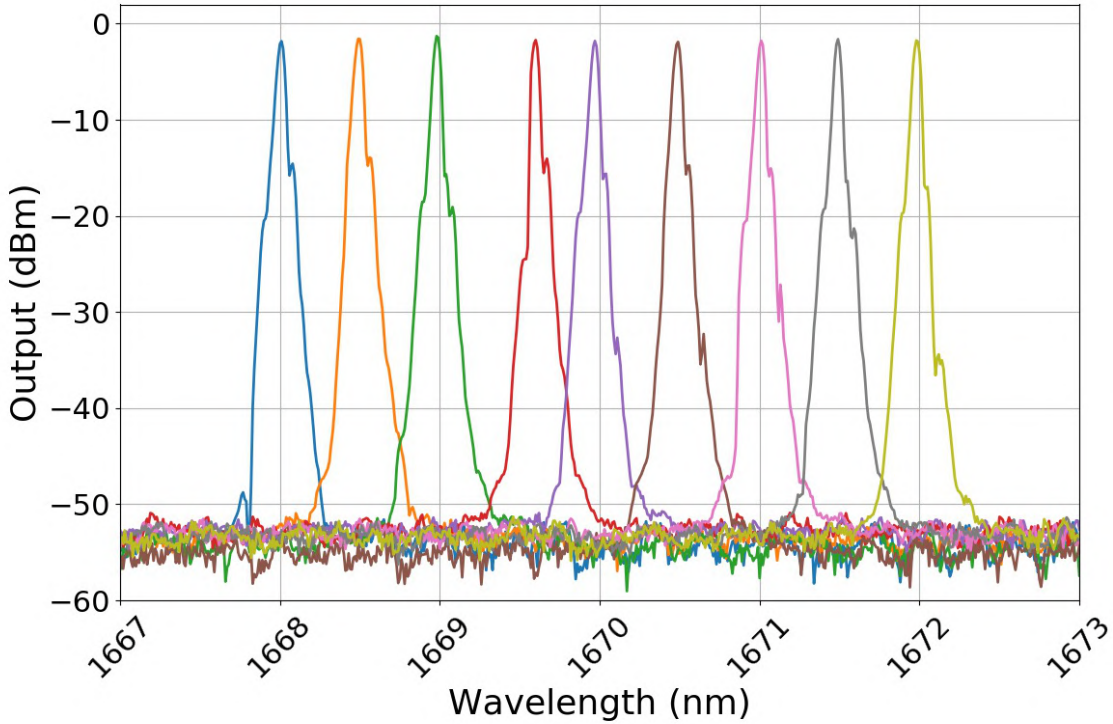
L-I-V measurement



Tuning of MRR

InP tunable laser at 1.67 µm





Output: -2 dBm from OSA,
Tuning range: 64 nm

Fine tuning

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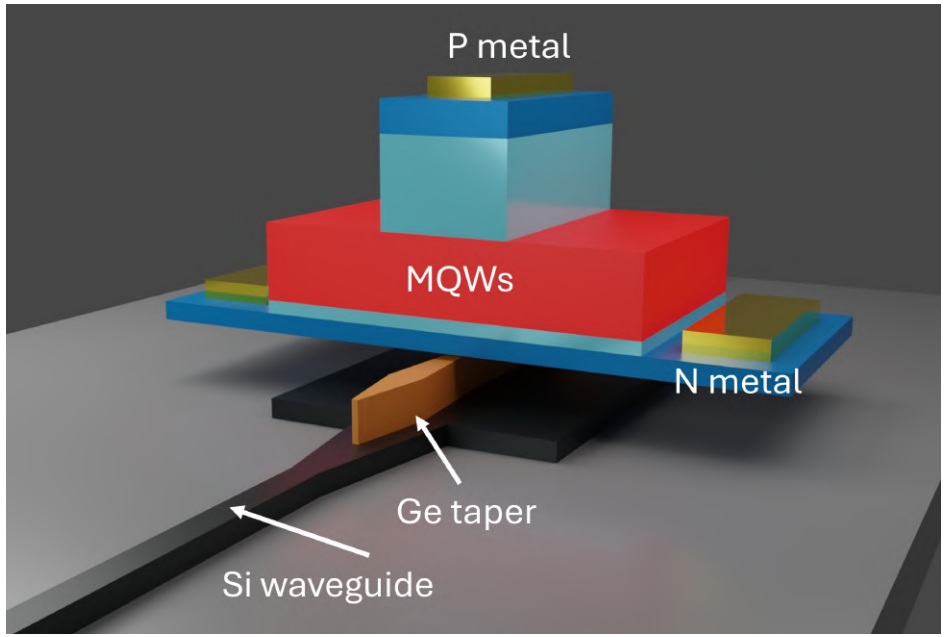
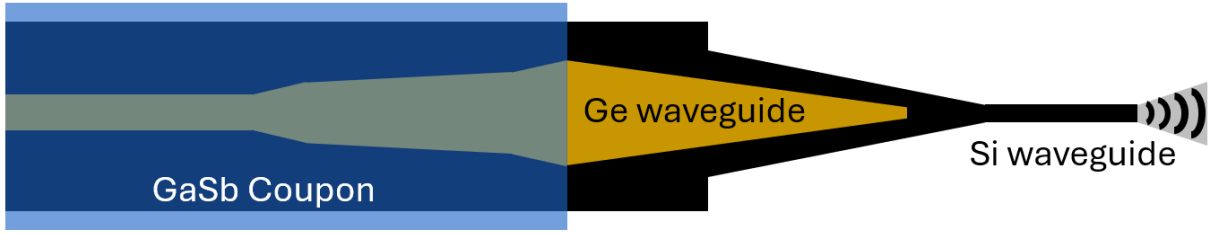
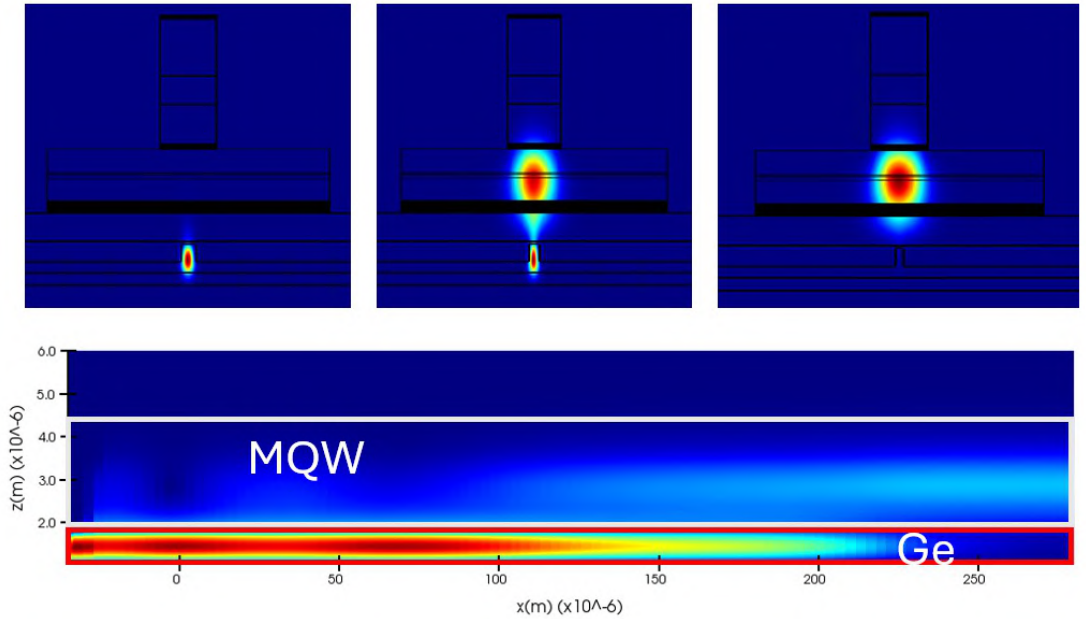
GaSb laser at 2.3 µm



Rendering of GaSb on Ge-SOI laser

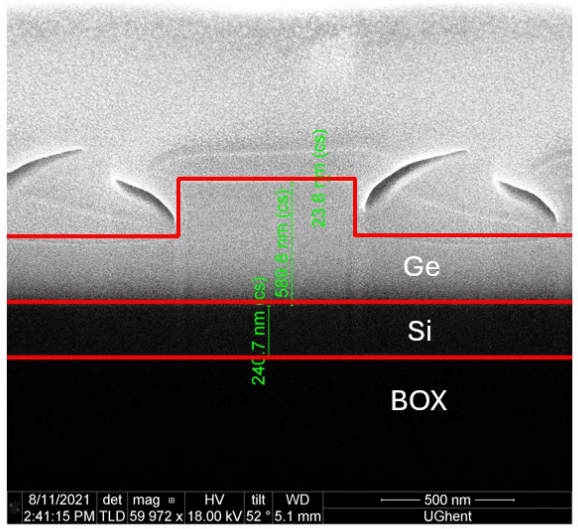
- Ge waveguide
- GaSb SOA



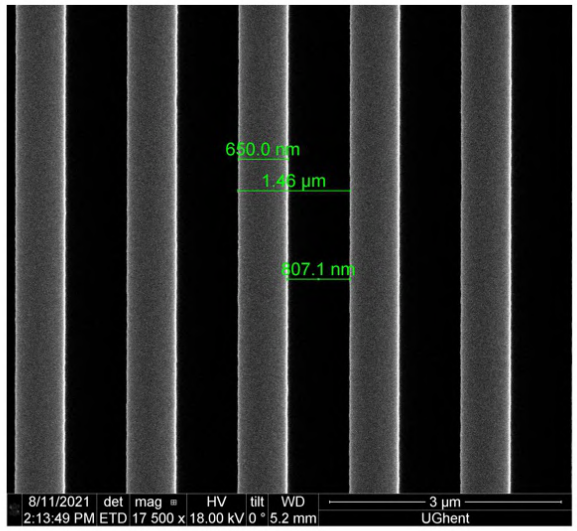


EME simulation of coupling

Germanium waveguides at 2.3 µm

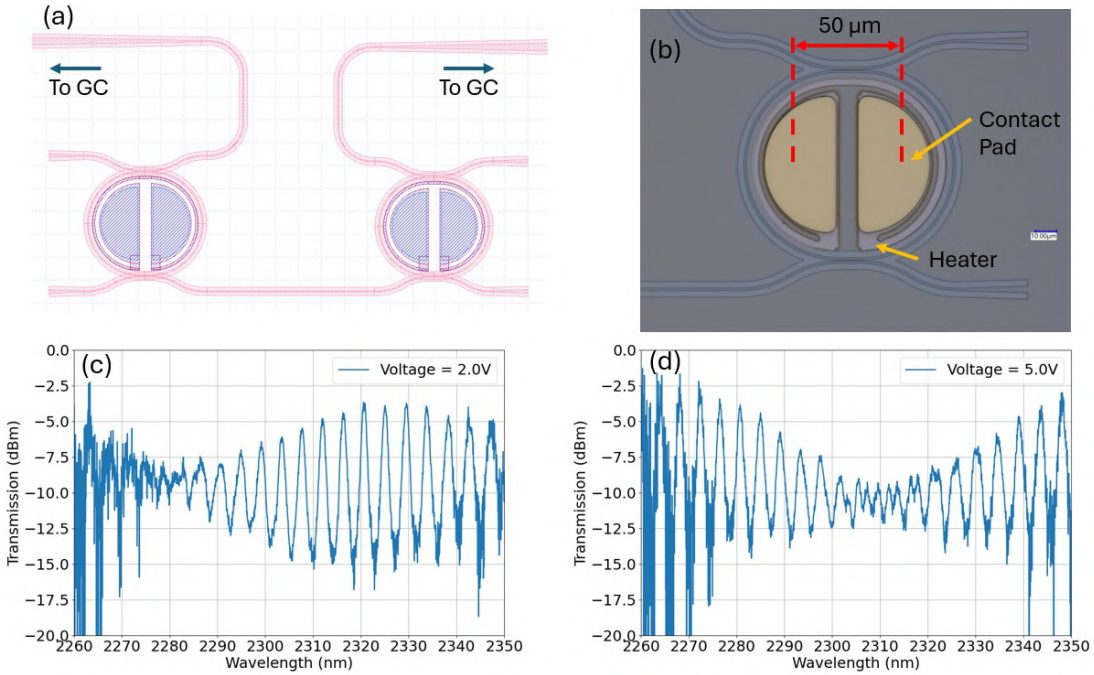


(a)



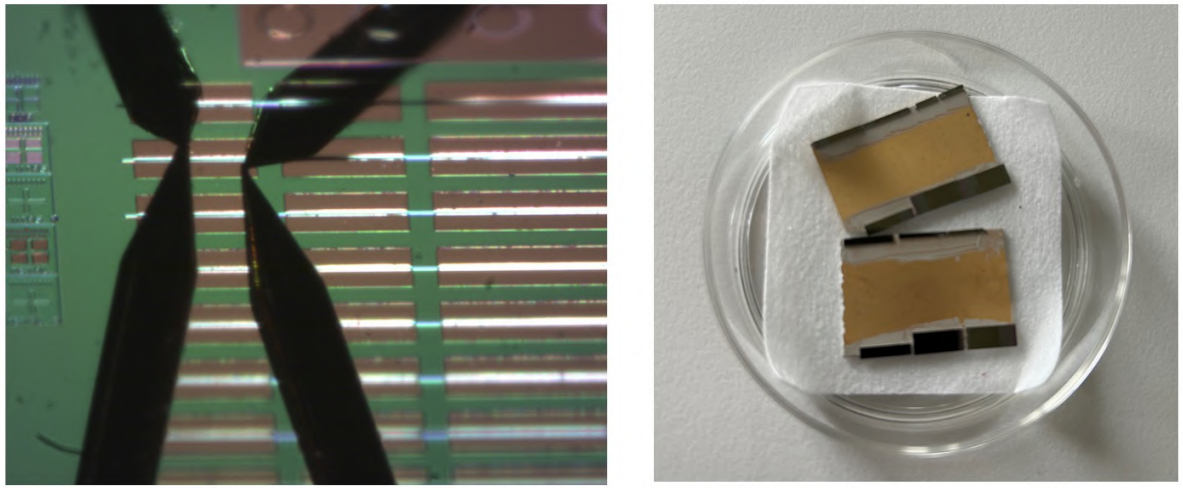
(b)

Ge waveguide / gratings,
loss = 3.75 dB/cm @ 2.3 µm

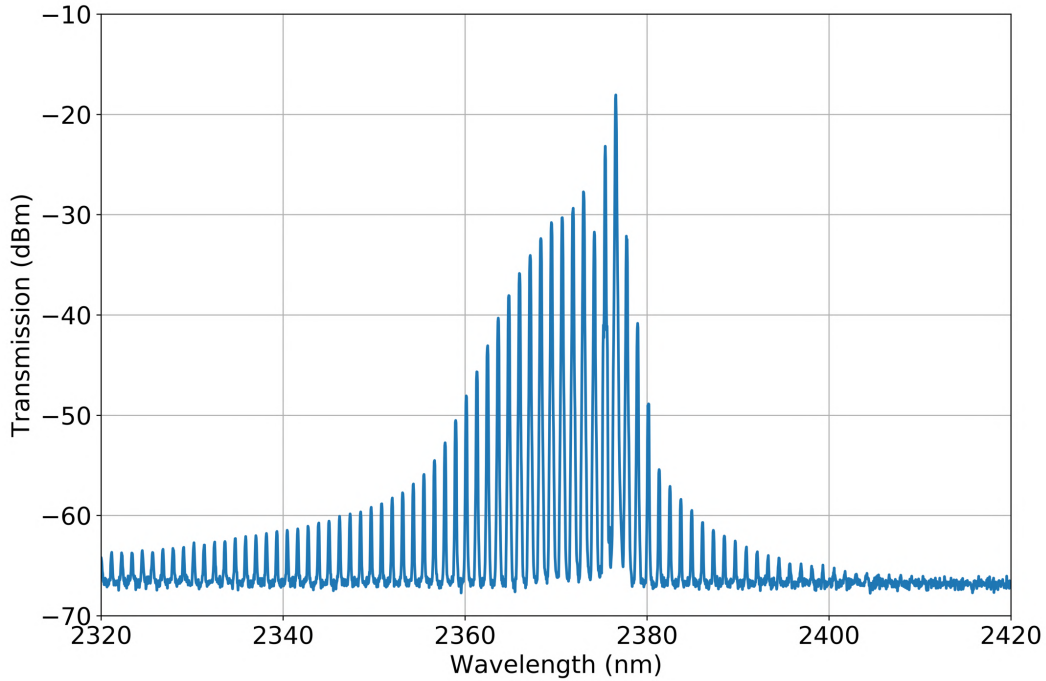


Measurement result of Ge rings

GaSb F-P laser at 2.3 µm

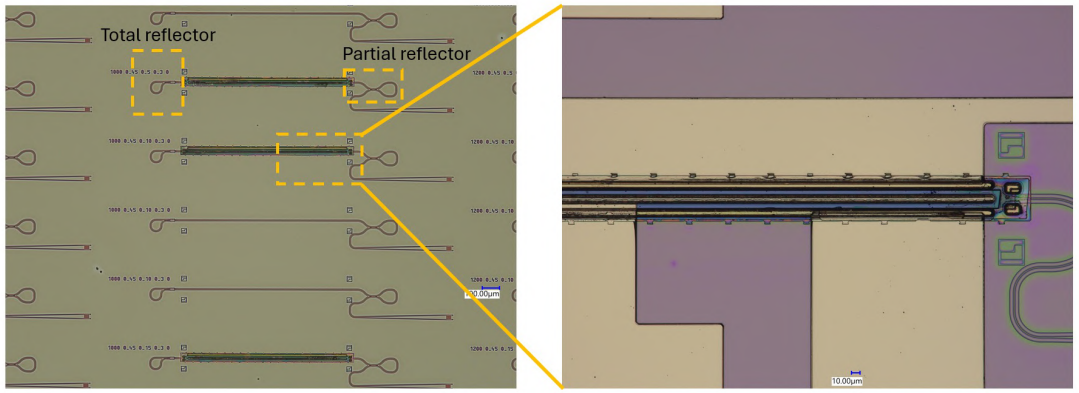


GaSb dummy F-P laser samples

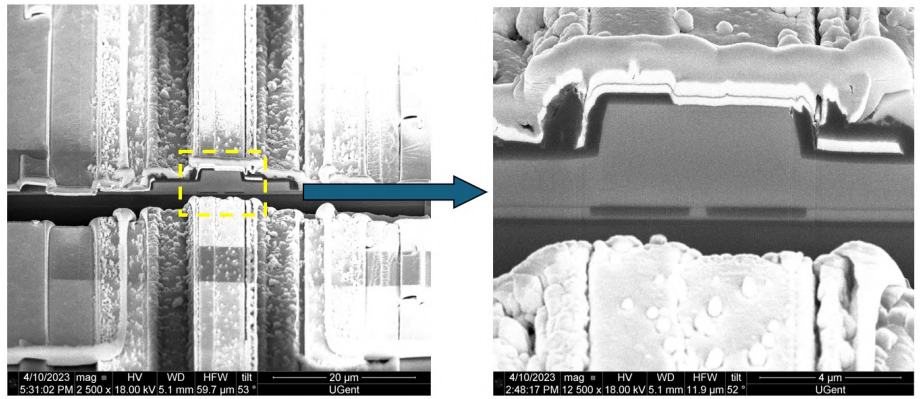


Measurement result of F-P laser

GaSb laser on GeSOI at 2.3 µm



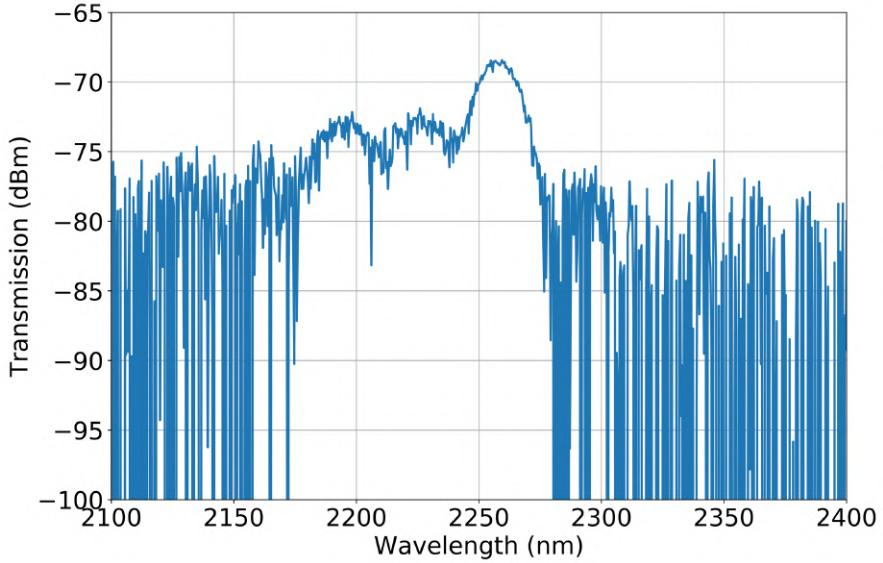
(a) (b)



(a) (b)

Process of GaSb laser on Ge-SOI

Measurement result: No lasing



- Mirror reflectivity
- Coupling efficiency
- Interface quality

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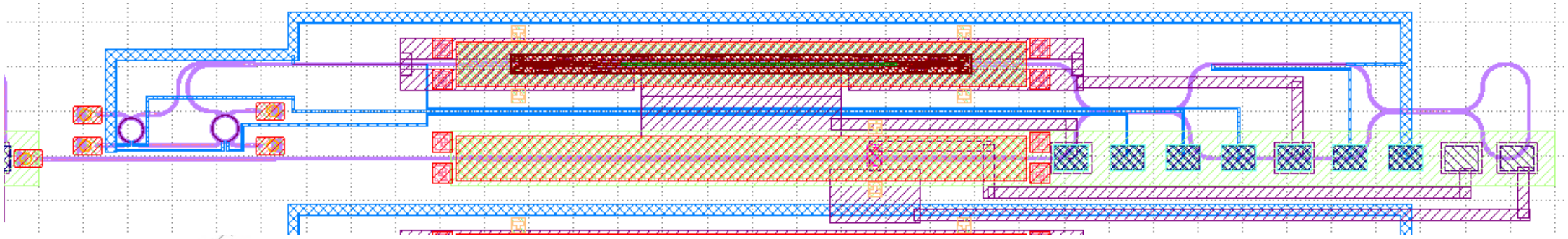
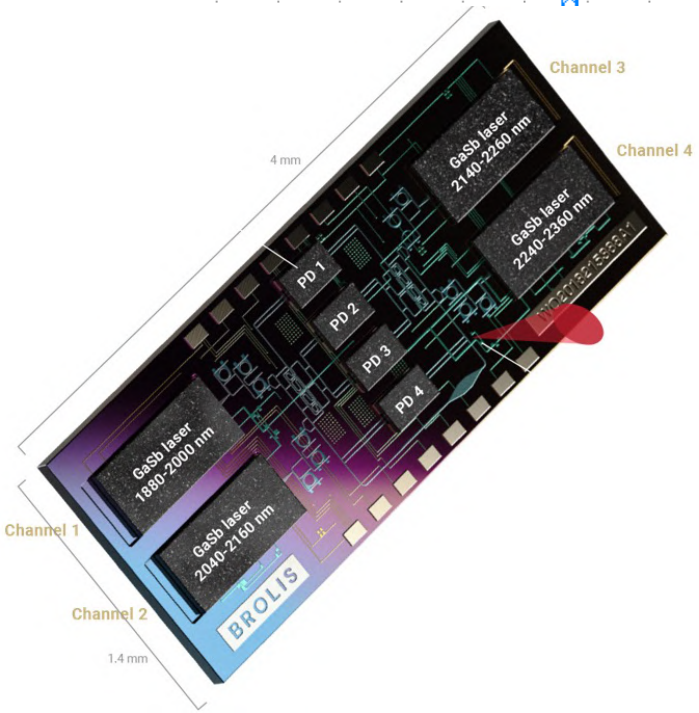
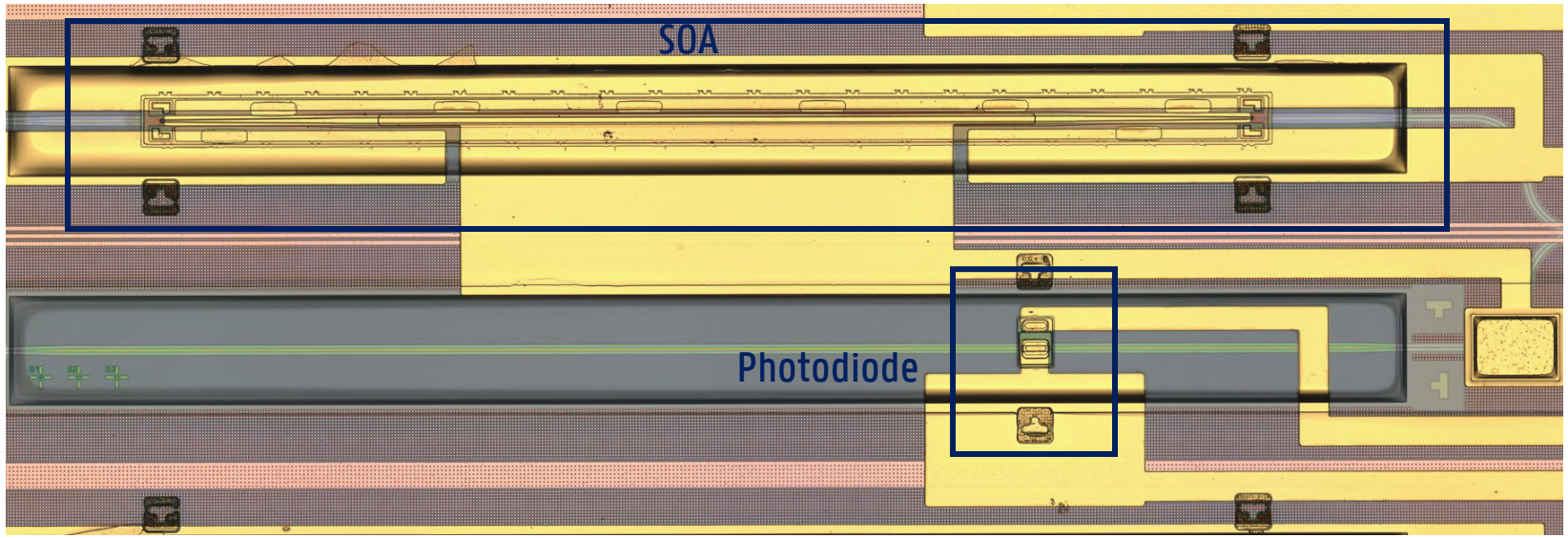
Outlook: Co-integration of laser and PD







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Summary

- GaSb Photodiode for 2.x µm
- InP laser for 1.67 µm
- GaSb laser for 2.x µm
- Co-integration of laser and photodiode

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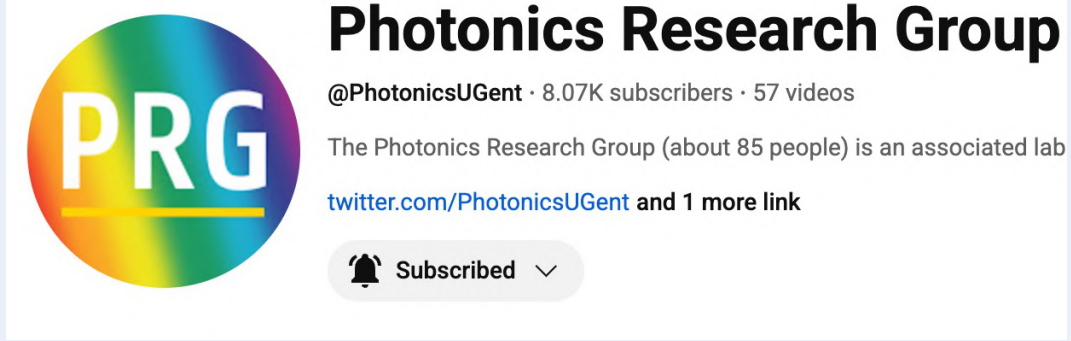

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