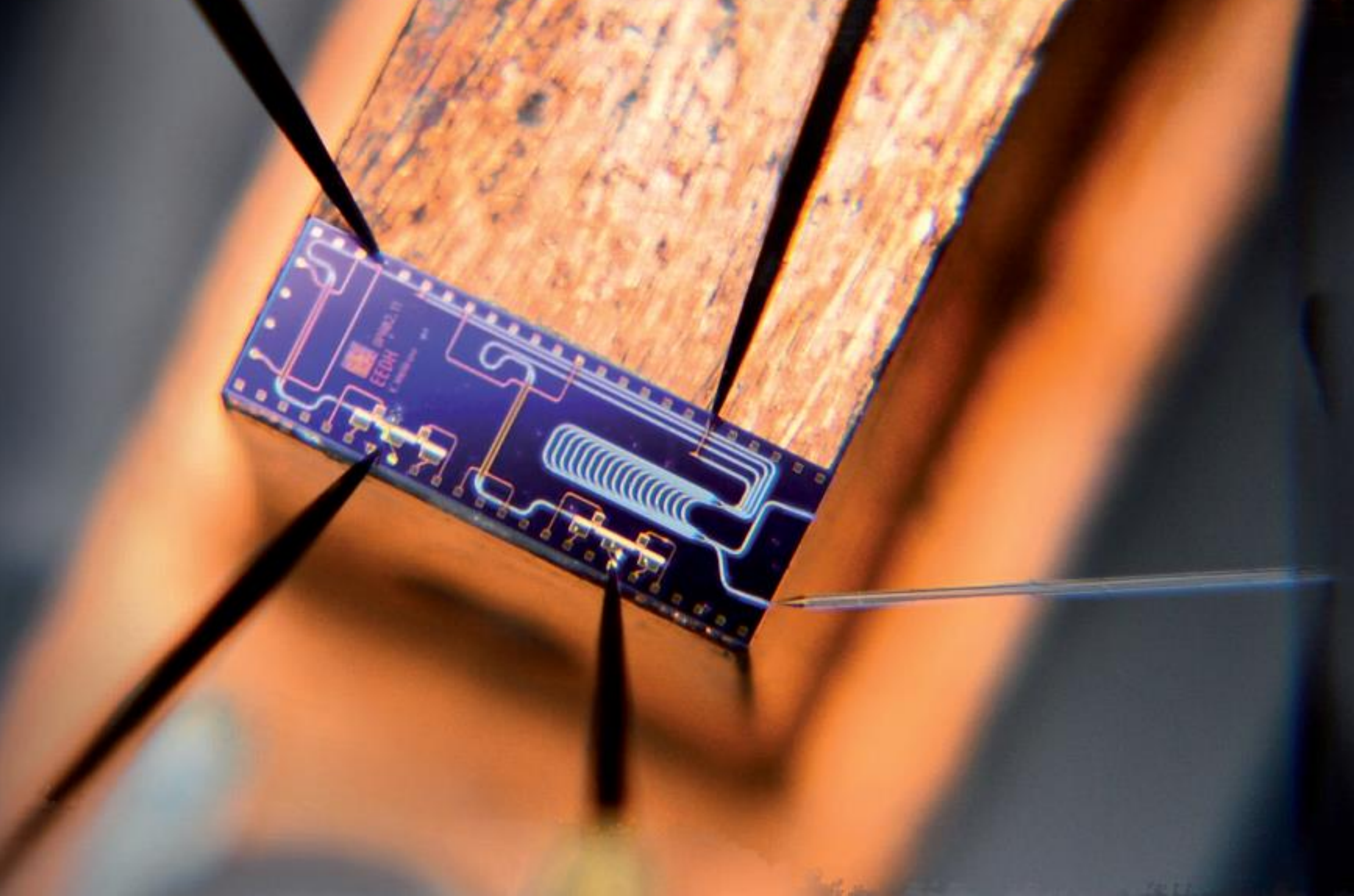
PHOTONIC INTEGRATED CIRCUITS
- toward new spectral ranges and new application fields

Ryszard Piramidowicz

POLITECHNIKA WARSZAWSKA
WARSAW UNIVERSITY OF TECHNOLOGY

VIGO PHOTONICS



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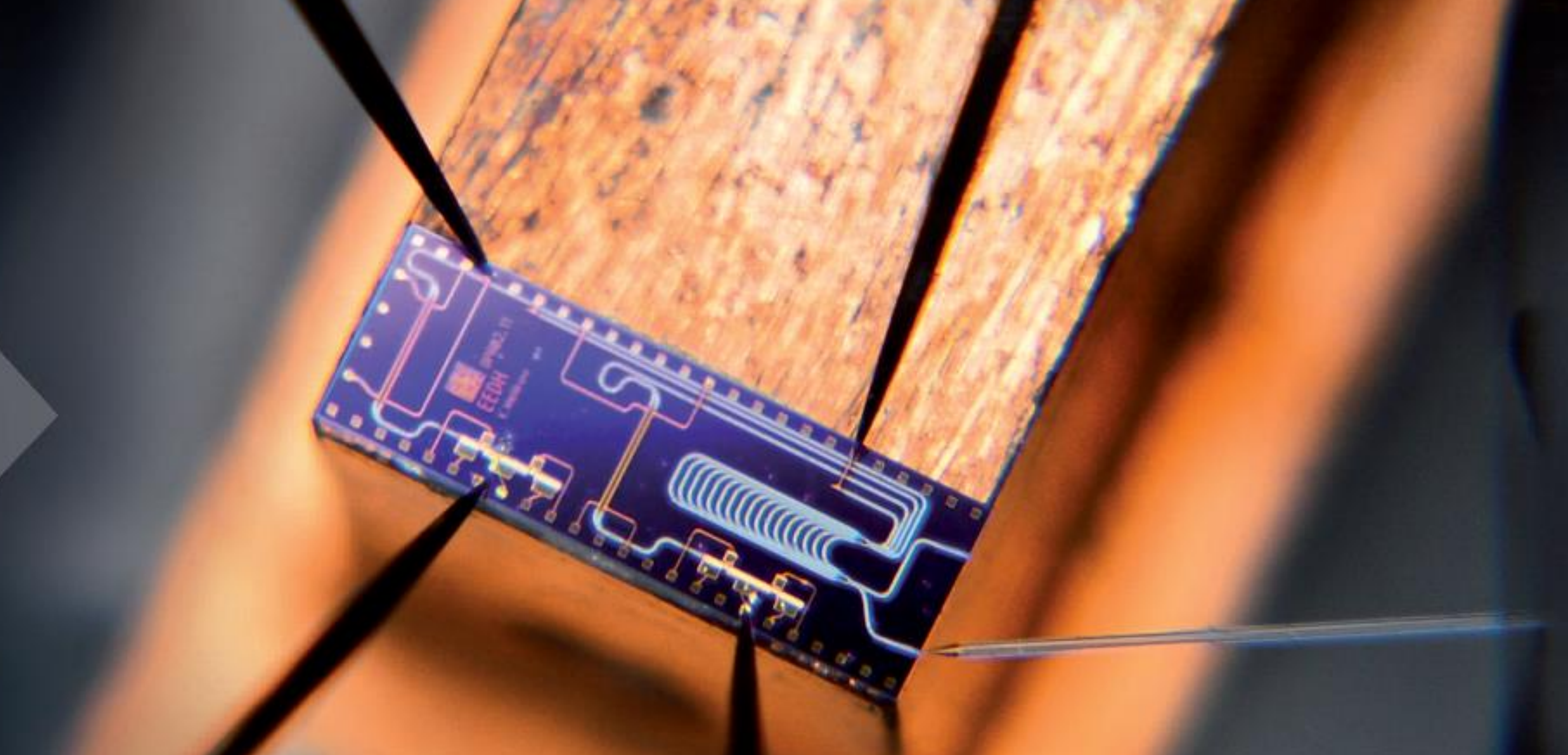
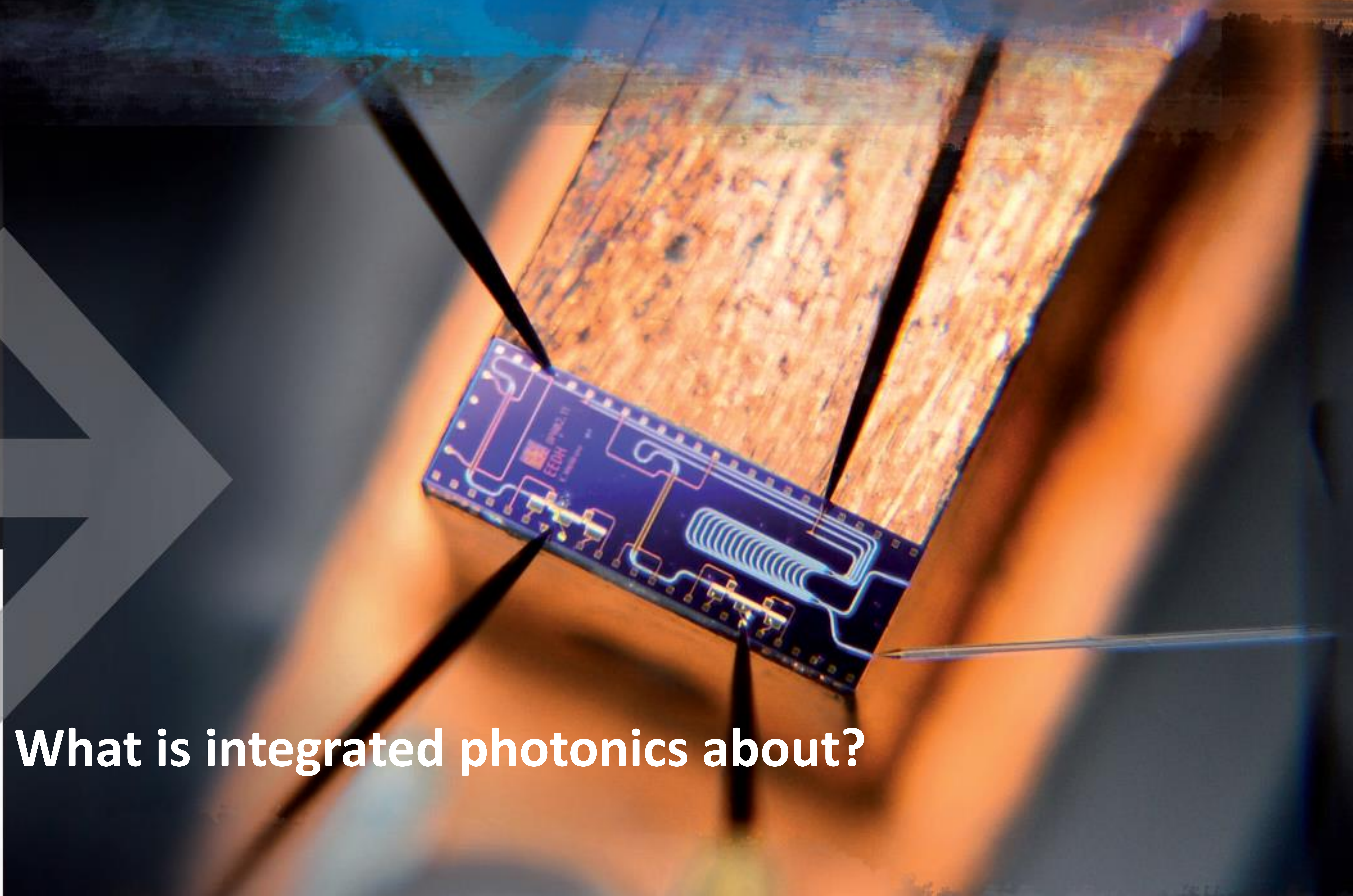


S. STOPIŃSKI, K. ANDERS, A. JUSZA, M. LELIT, A. POŁATYŃSKI,
A. BIENIEK-KACZOREK, A. PAŚNIKOWSKA,
P. WIŚNIEWSKI, M. SŁOWIKOWSKI, M. JUCHNIEWICZ,
J. JUREŃCZYK, M. LIEBERT, K. PIERŚCIŃSKI, D. PIERŚCIŃSKA



What is integrated photonics about?

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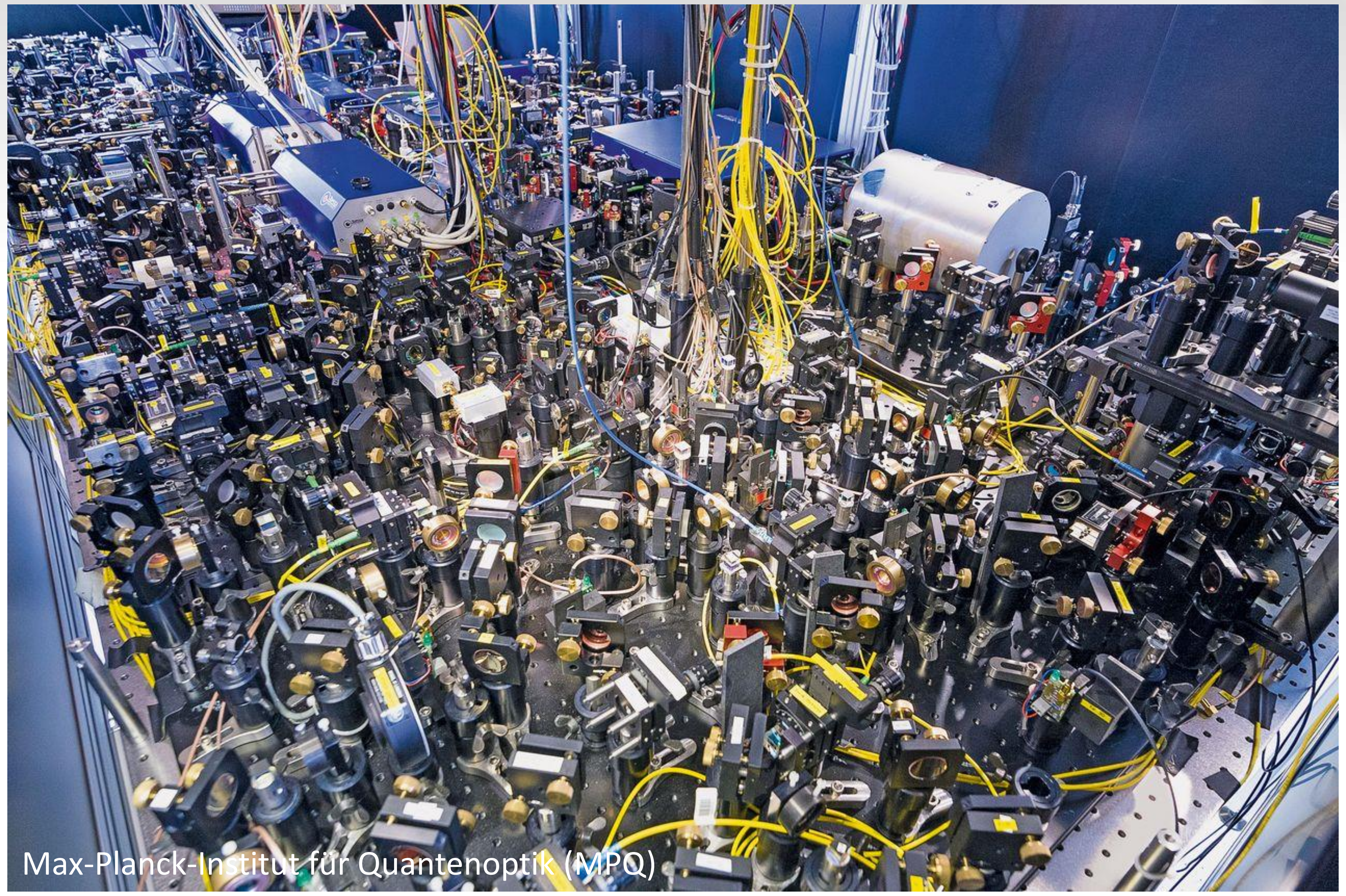
Integrated Photonics at glance



Max-Planck-Institut für Quantenoptik (MPQ)

Advantages:

- compactness
- low power consumption
- high reliability
- reduction of packaging costs
- low manufacturing and exploitation costs

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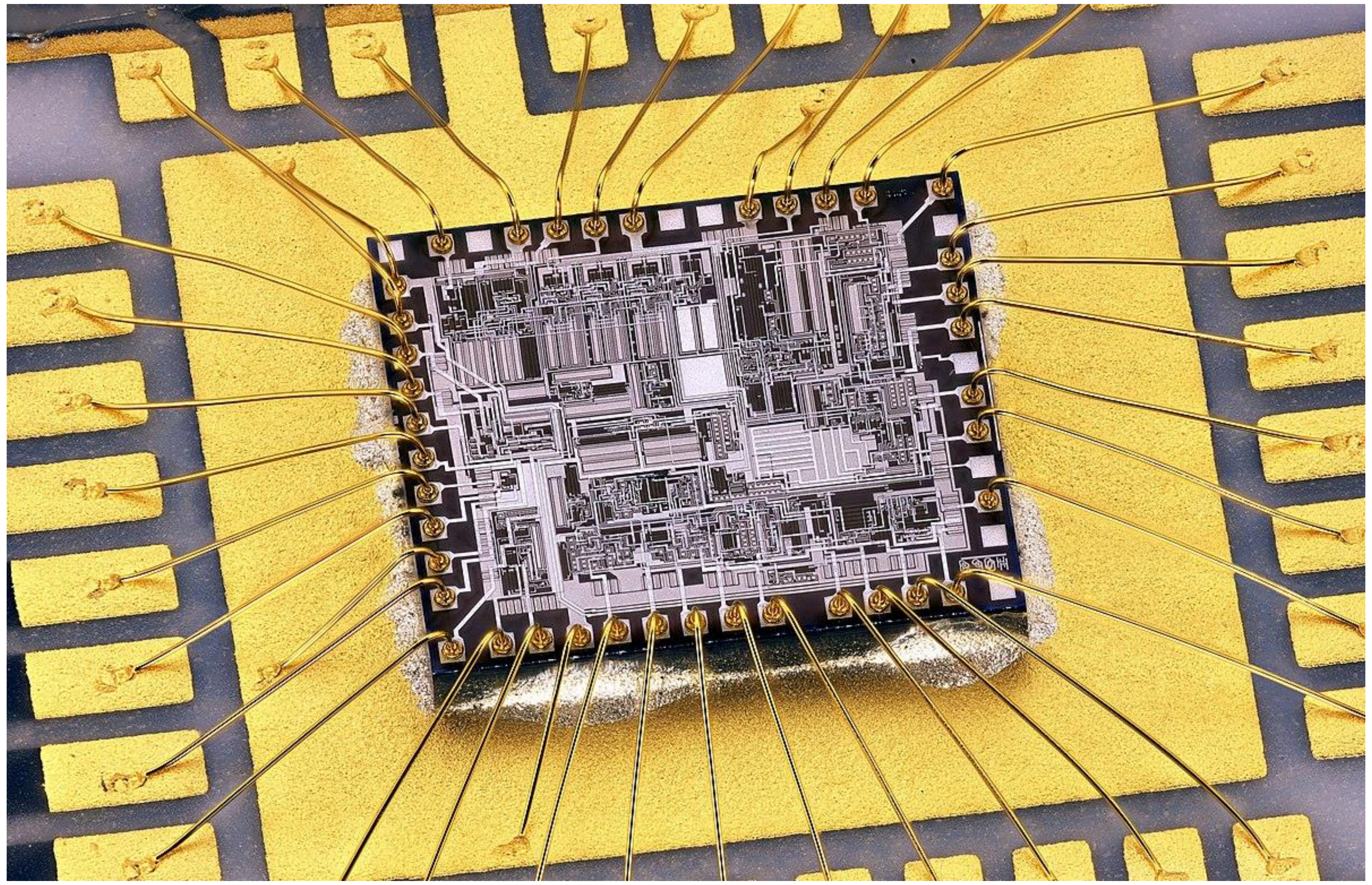
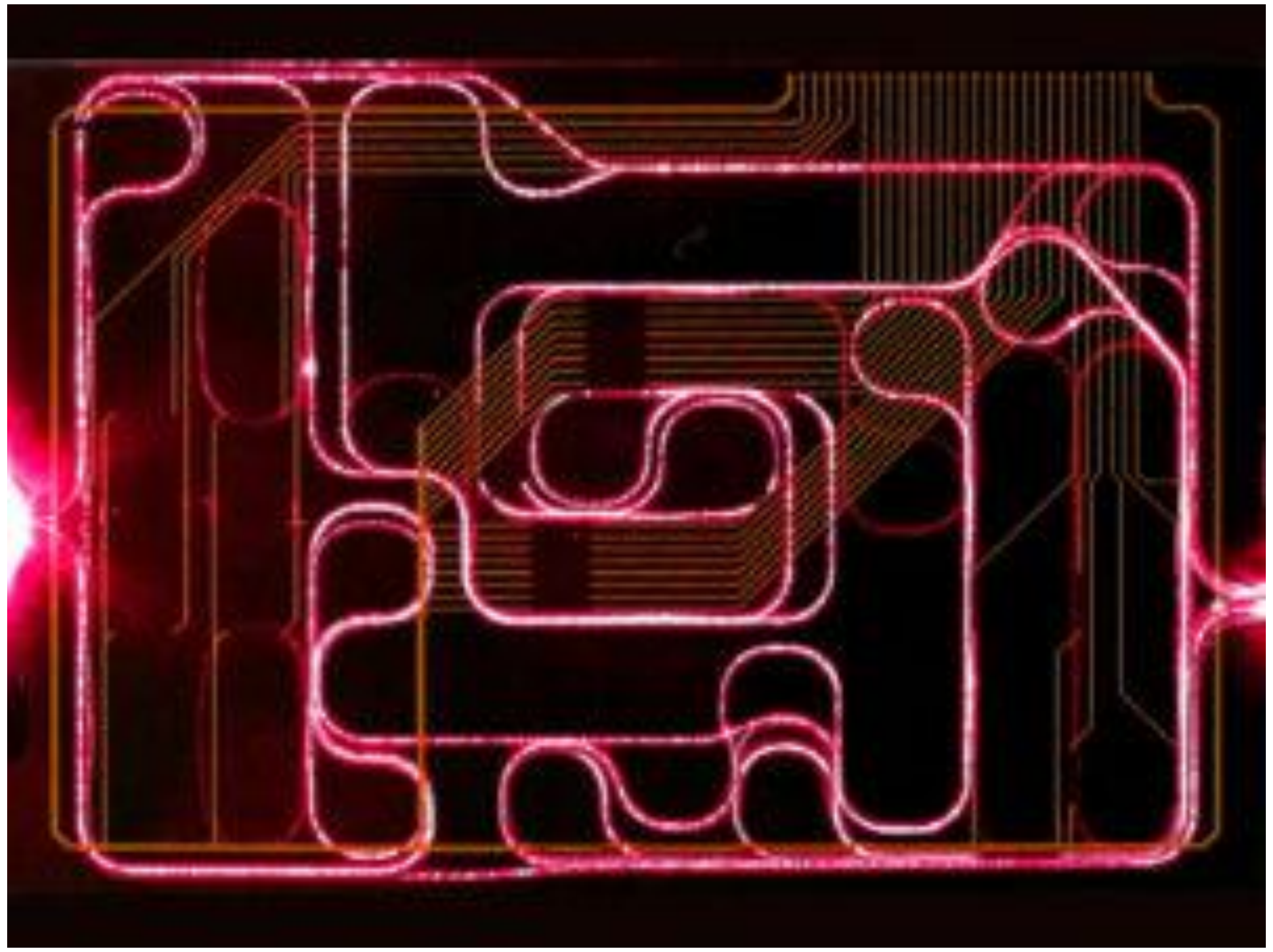
Integrated Photonics at glance

Integrated Electronics



Integrated Photonics



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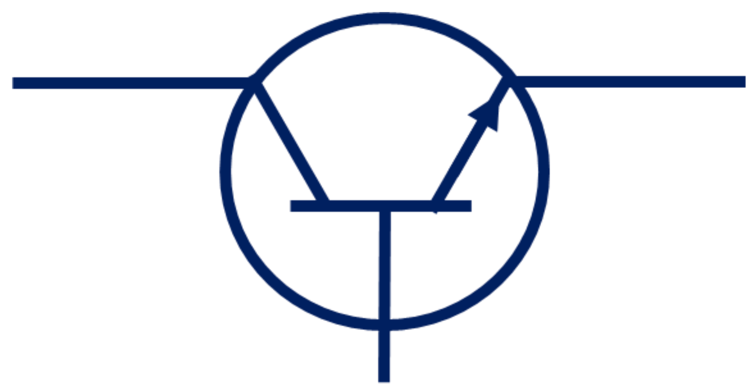
Integrated Photonics at glance

Electronic Building Blocks



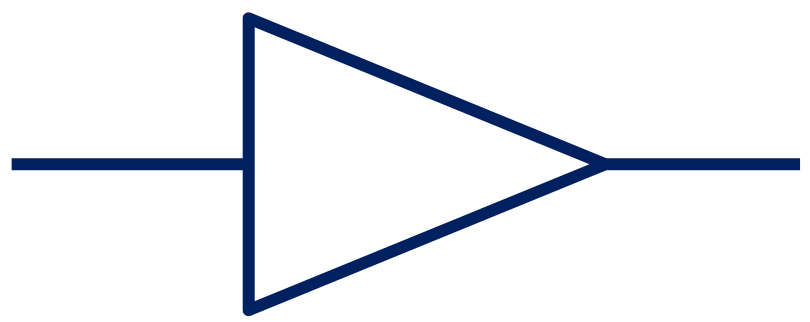
transistor

capacitor

resistor

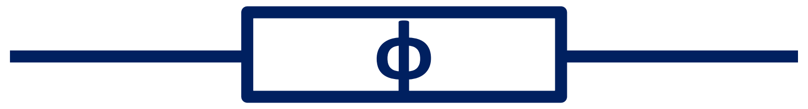
electrical connection

Photonic Building Blocks



optical amplifier

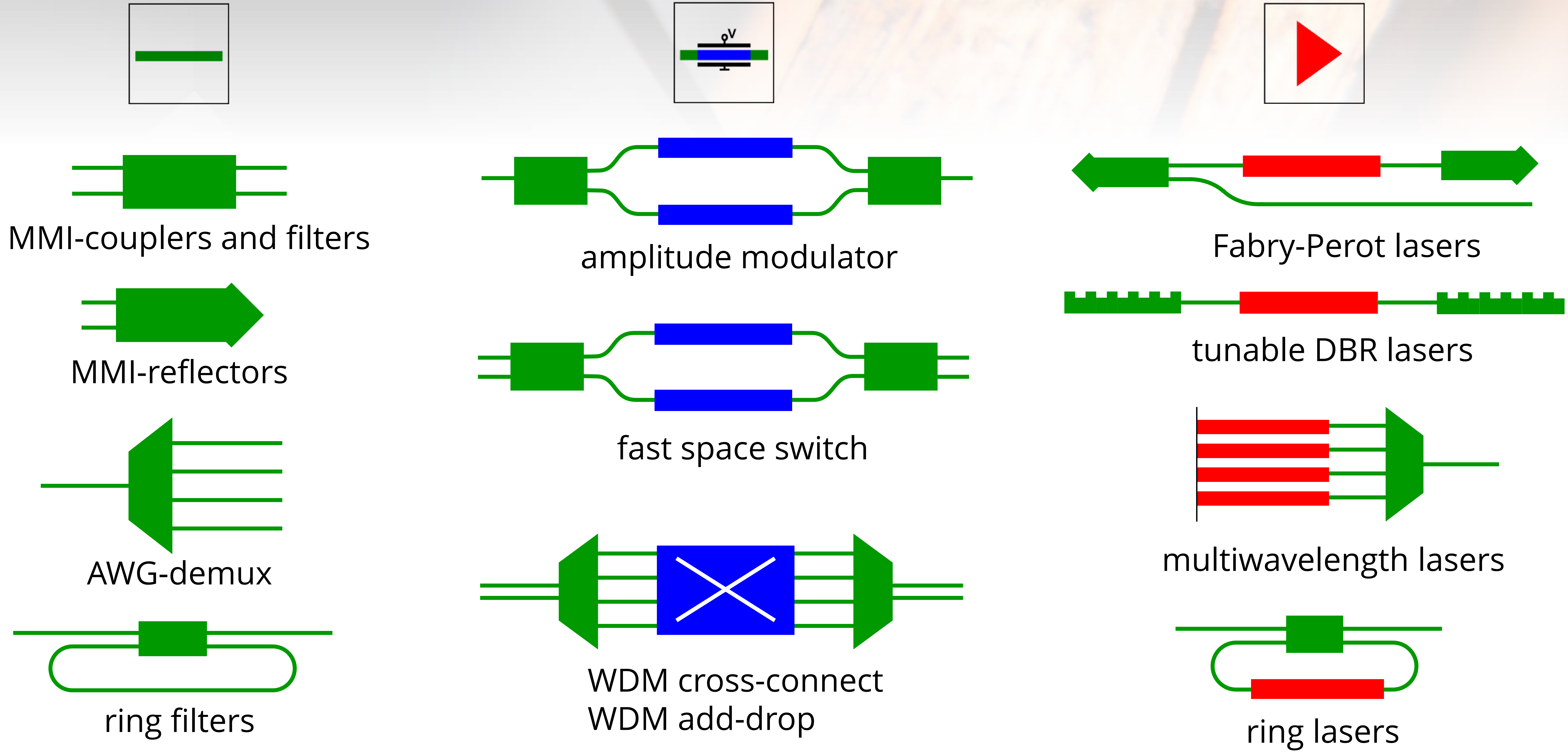
polarization converter



phase shifter

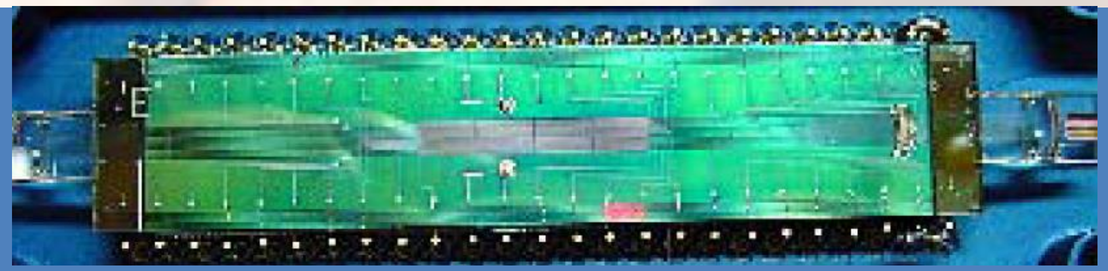
waveguide

Generic integration technology

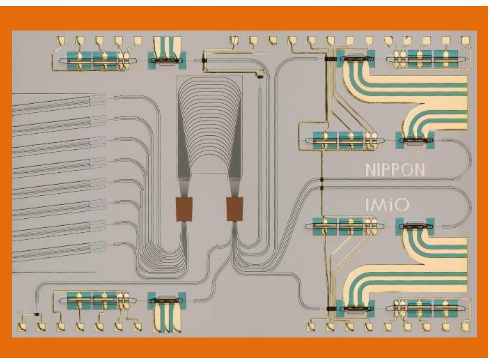


Technological platforms of integrated photonics

Si (silicon photonics)
passive components and devices


Si Multichannel modulator

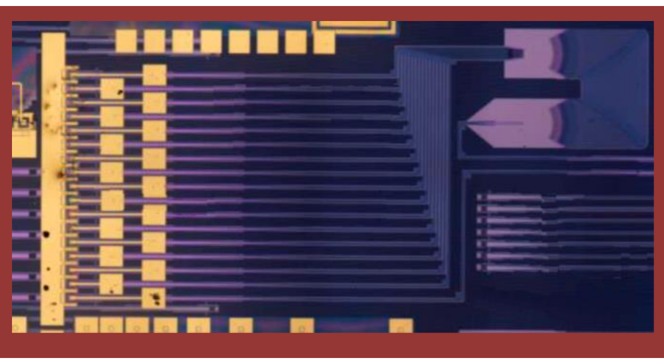
InP and related materials (InGaAsP)
active for 900–1800 nm window


InP multichannel transmitter

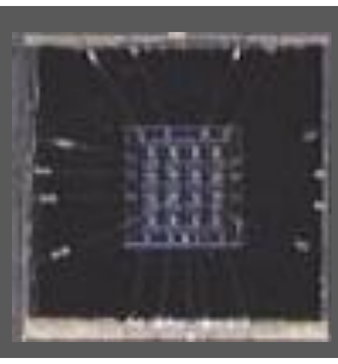
Si_3N_4 on SiO_2
passive


Si_3N_4 on SiO_2 optical ring resonator

Hybrid/heterogeneous
combined potential of various platforms


Si photonic AWG with integrated photodetectors

GaAs
active for 600–900 nm window


GaAs chip for cancer diagnose

Dielectric
(e.g. $LiNbO_3$; RE^{3+}-doped)


$LiNbO_3$ modulators

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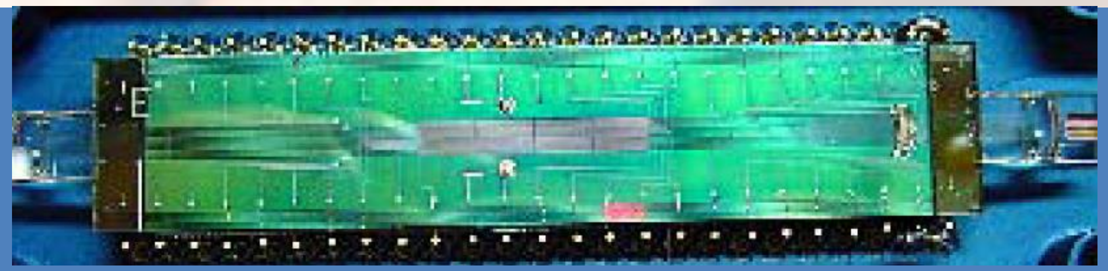

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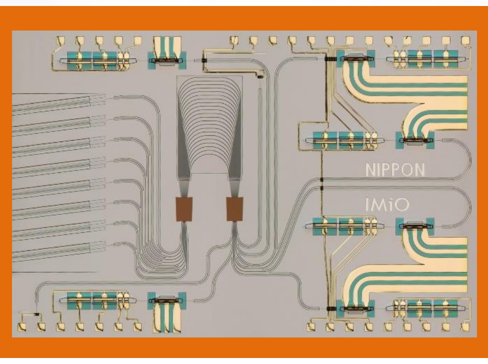

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Technological platforms of integrated photonics

	Indium phosphide (InP)	Silicon (SOI)	Silicon nitride (Si_3N_4)
Light generation and amplification	Yes	No (hybrid integration)	No (hybrid integration)
Light modulation	Electro-optic effect Carrier injection/depletion Electro-absorption Thermo-optic	No electro-optic effect Carrier injection/depletion Electro-absorption Thermo-optic	No electro-optic effect No carrier injection/depletion No electro-absorption Thermo-optic
Light detection @1550 nm	InGaAs/InGaAsP PIN photodiodes	Ge photodiodes	No
Index contrast	Low (large bending radii)	High (small bending radii)	Moderate (moderate bending radii)
Propagation loss @1550 nm	~1-2 dB/cm	0.1-0.5 dB/cm	0.02-0.5 dB/cm
Wavelength range	0.9 – 1.7 µm	1.2 – 3.7 µm	0.4 – 3.7 µm

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Technological platforms of integrated photonics

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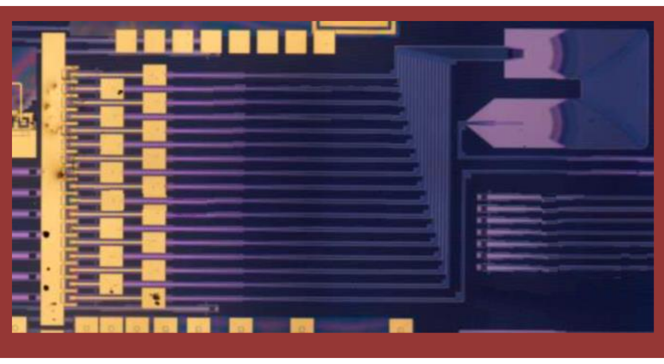

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VIGO PHOTONICS

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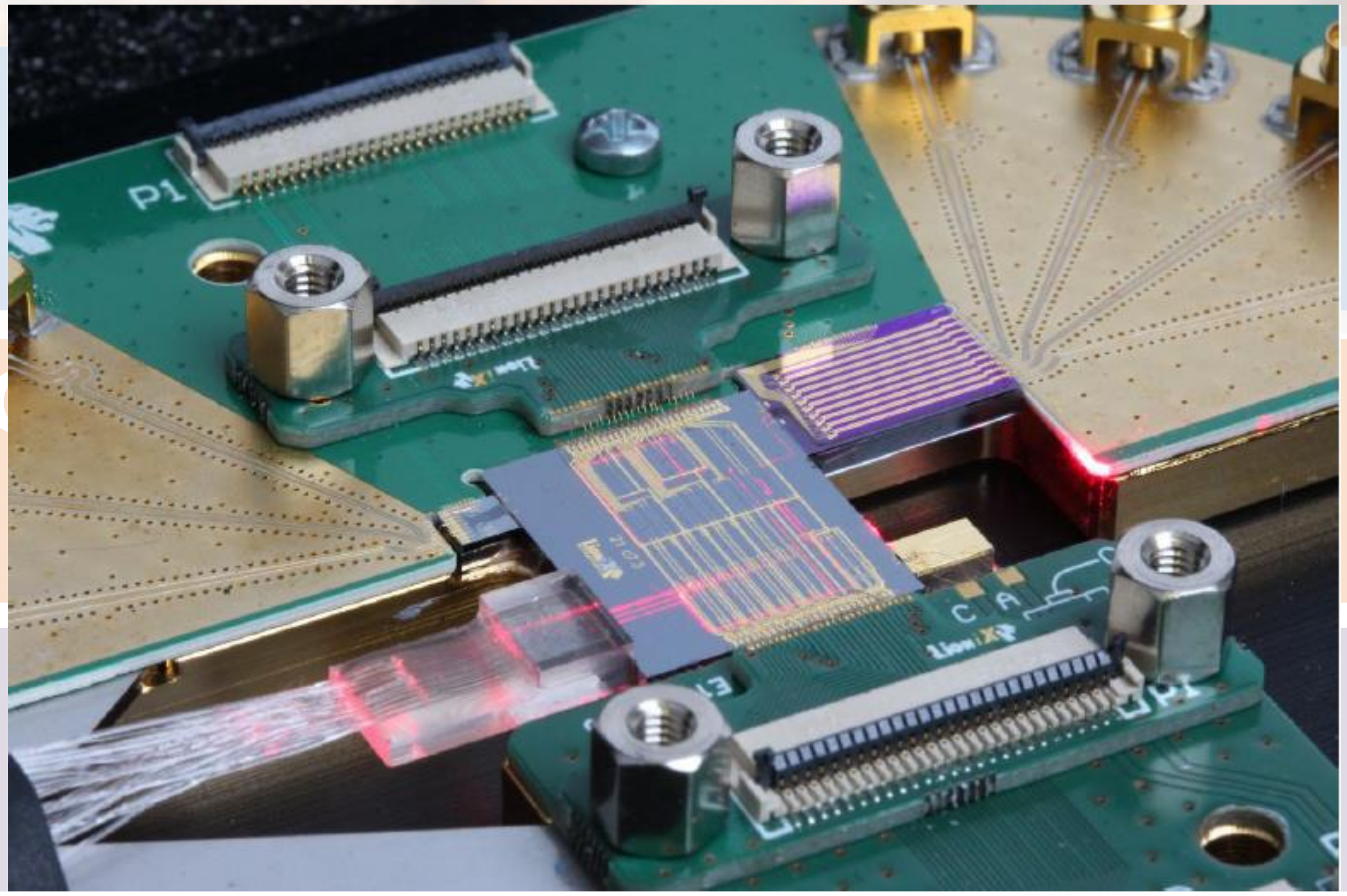
Technological platforms of integrated photonics



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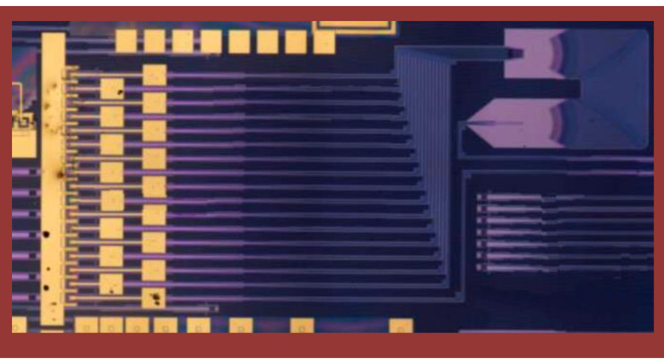

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VIGO PHOTONICS

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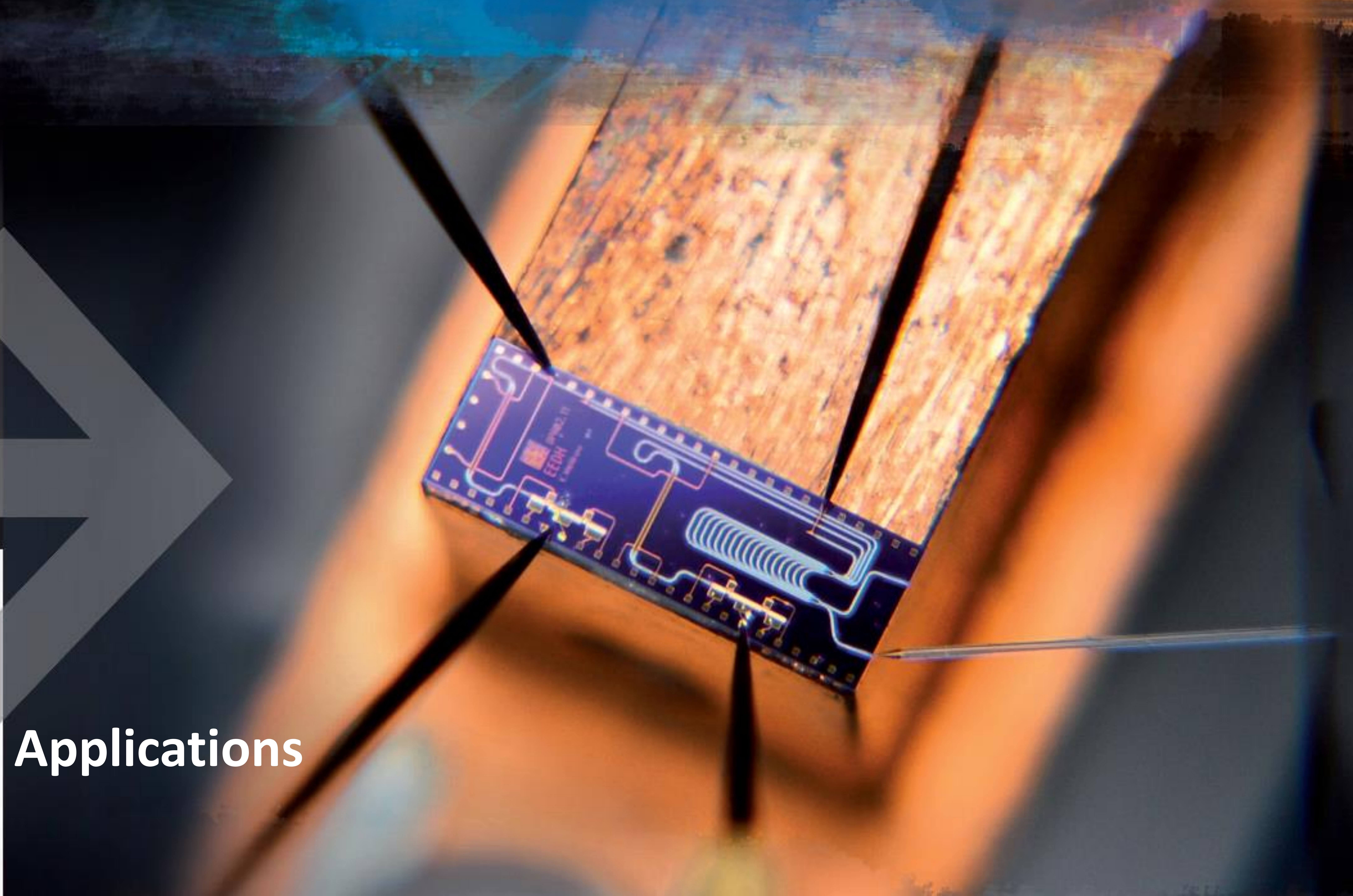
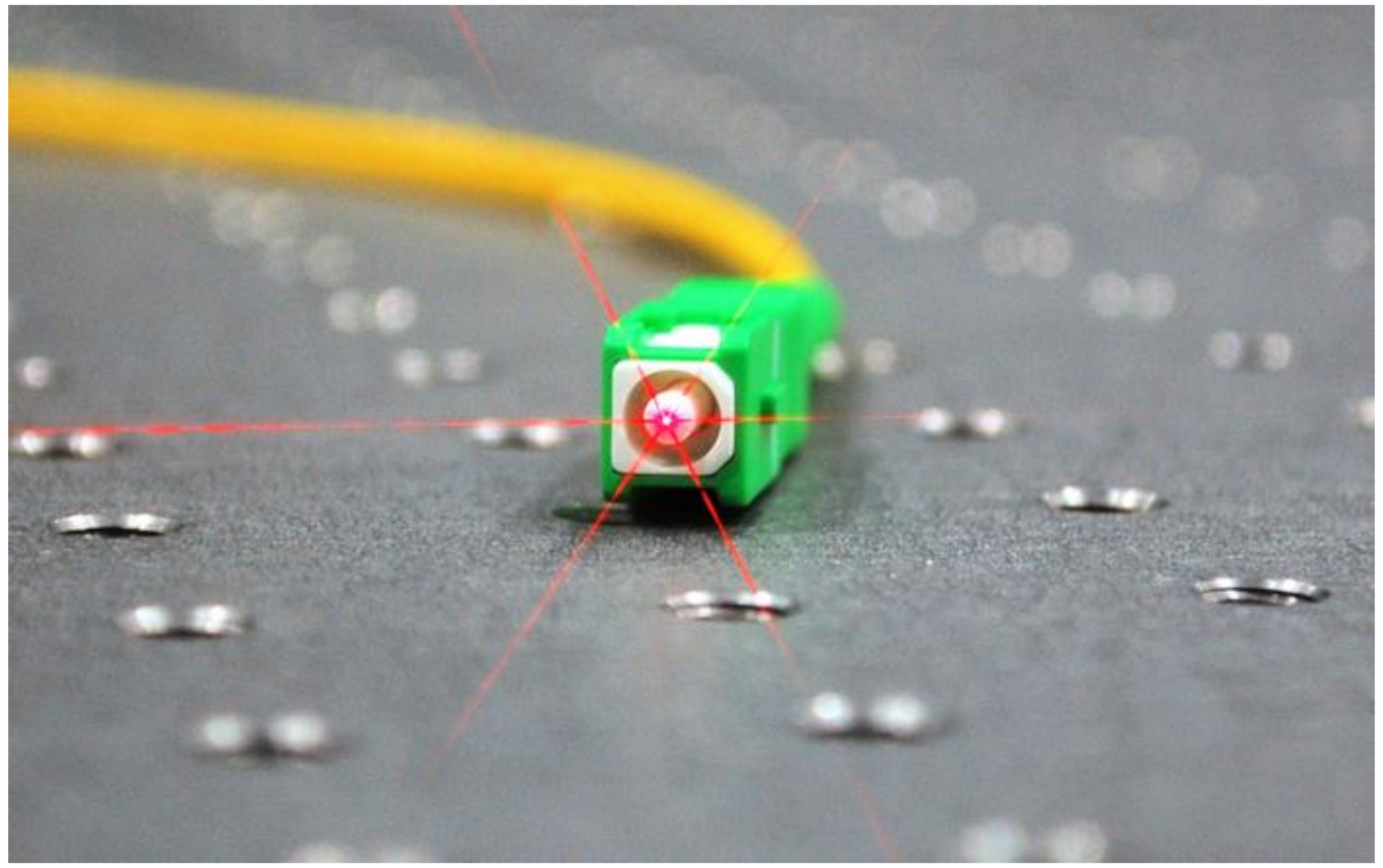


Applications

Applications

- optical communication (fiber-optic communication systems)
- data communication (data centers)
- others



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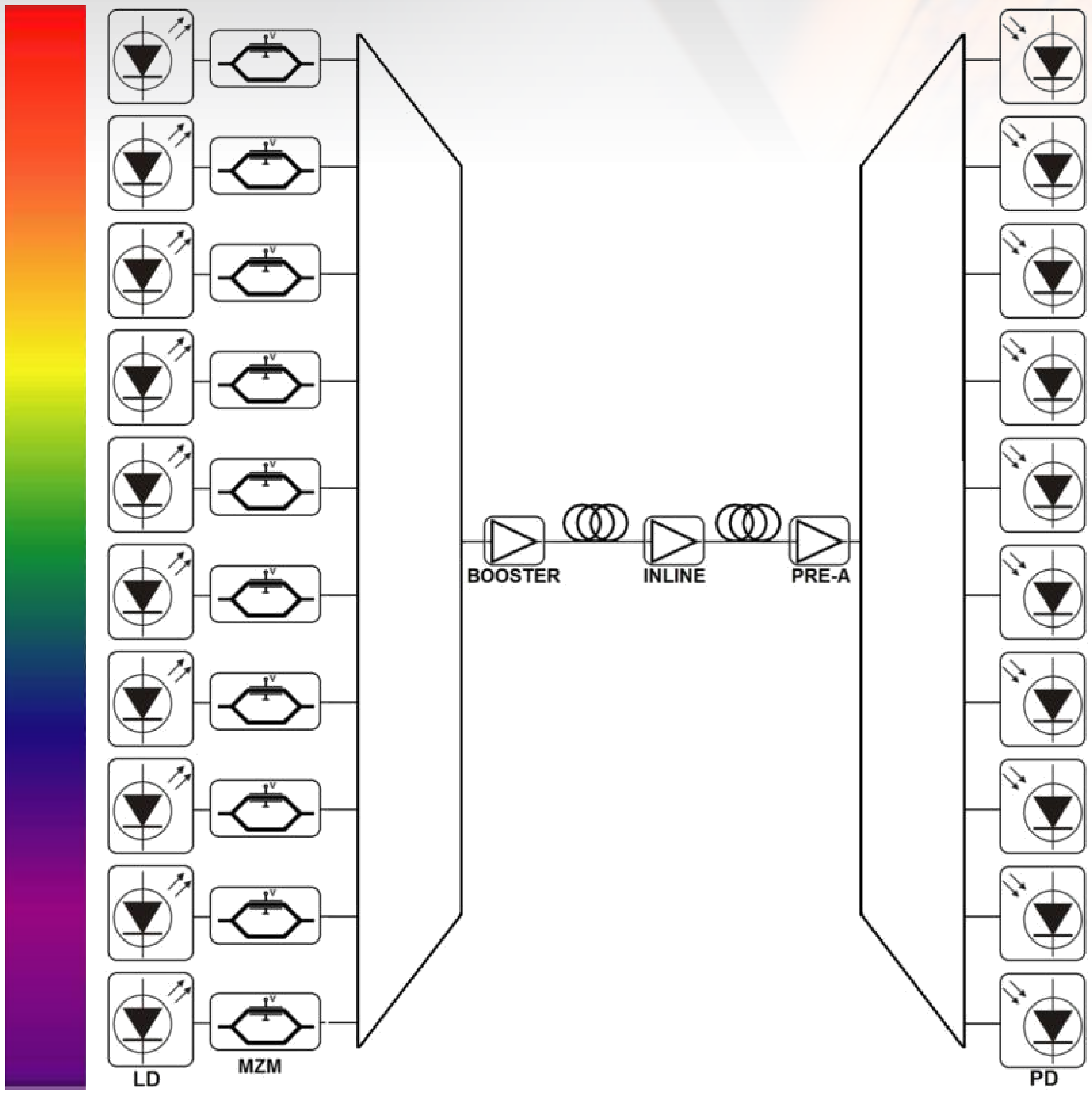
2003 - the proposal that changed the telecom market forever…

infinera



10 wavelengths

Tx module:

10 Laser diodes (InGaAsP)

10 modulators ($LiNbO_3$)

Booster amplifier (EDFA or InGaAsP SOA)

Rx module:

Pre-amplifier (EDFA or InGaAsP SOA)

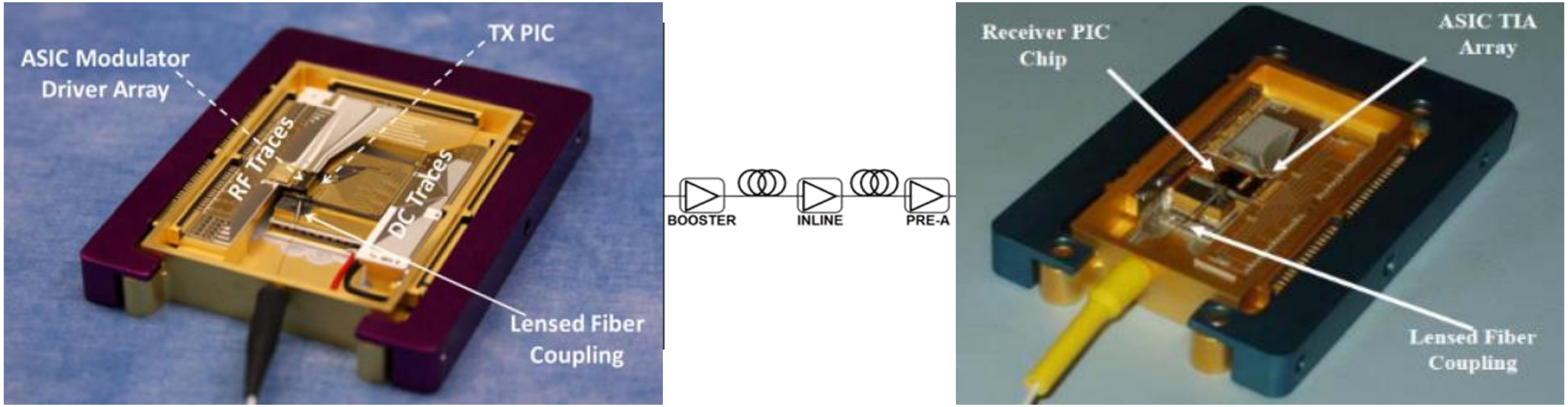
10 photodiodes (InGaAs)

D. Welch, Next Generation Digital Optical Systems, Berkeley Optoelectronics Seminar Series, 2006

Optical communication

WDM system in a size of matchbox (InP technology) 2006

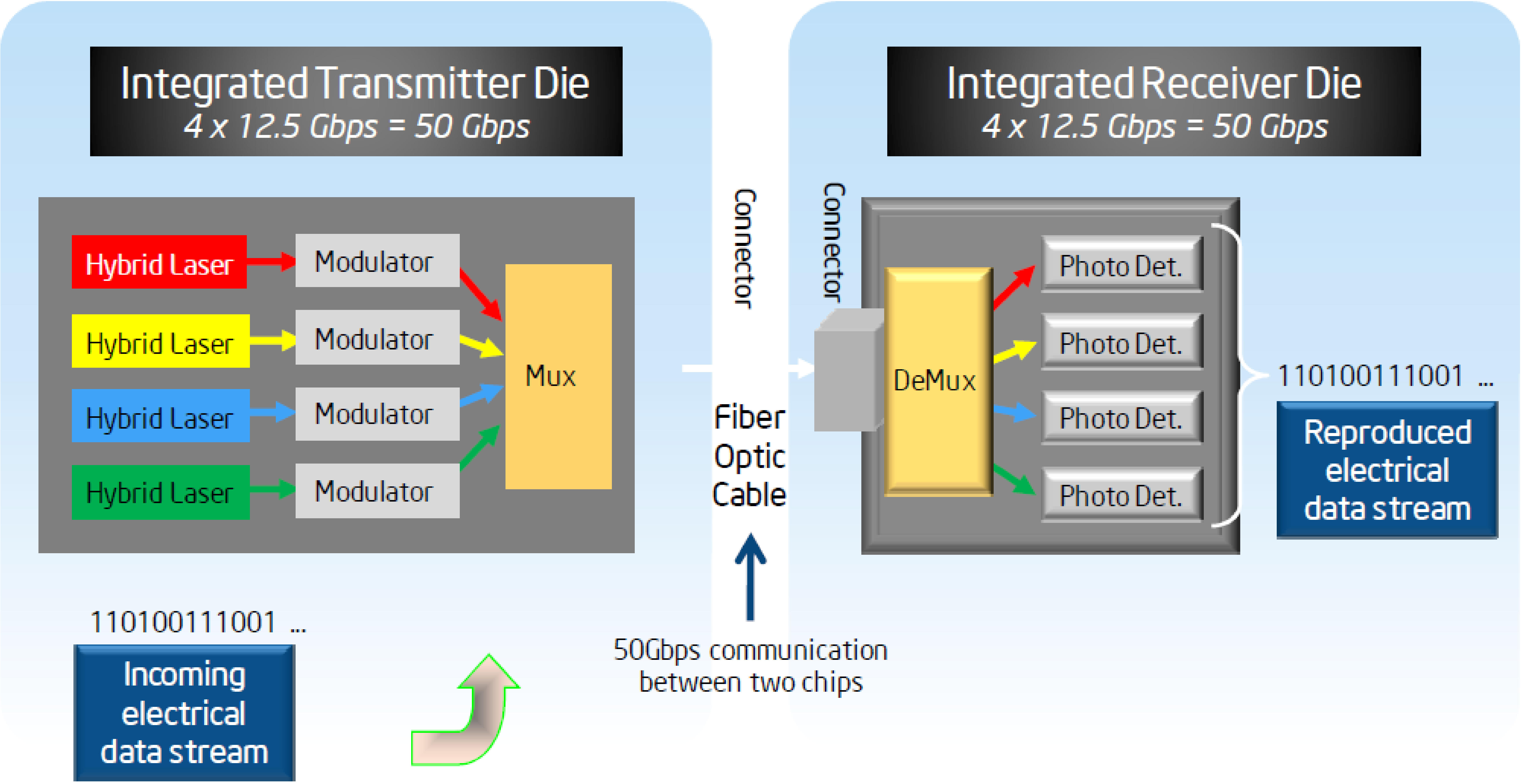
infinera



D. Welch, Next Generation Digital Optical Systems, Berkeley Optoelectronics Seminar Series, 2006

Early followers - data communication (silicon photonics)

Intel WDM data link - 50 Gb/s (2010)



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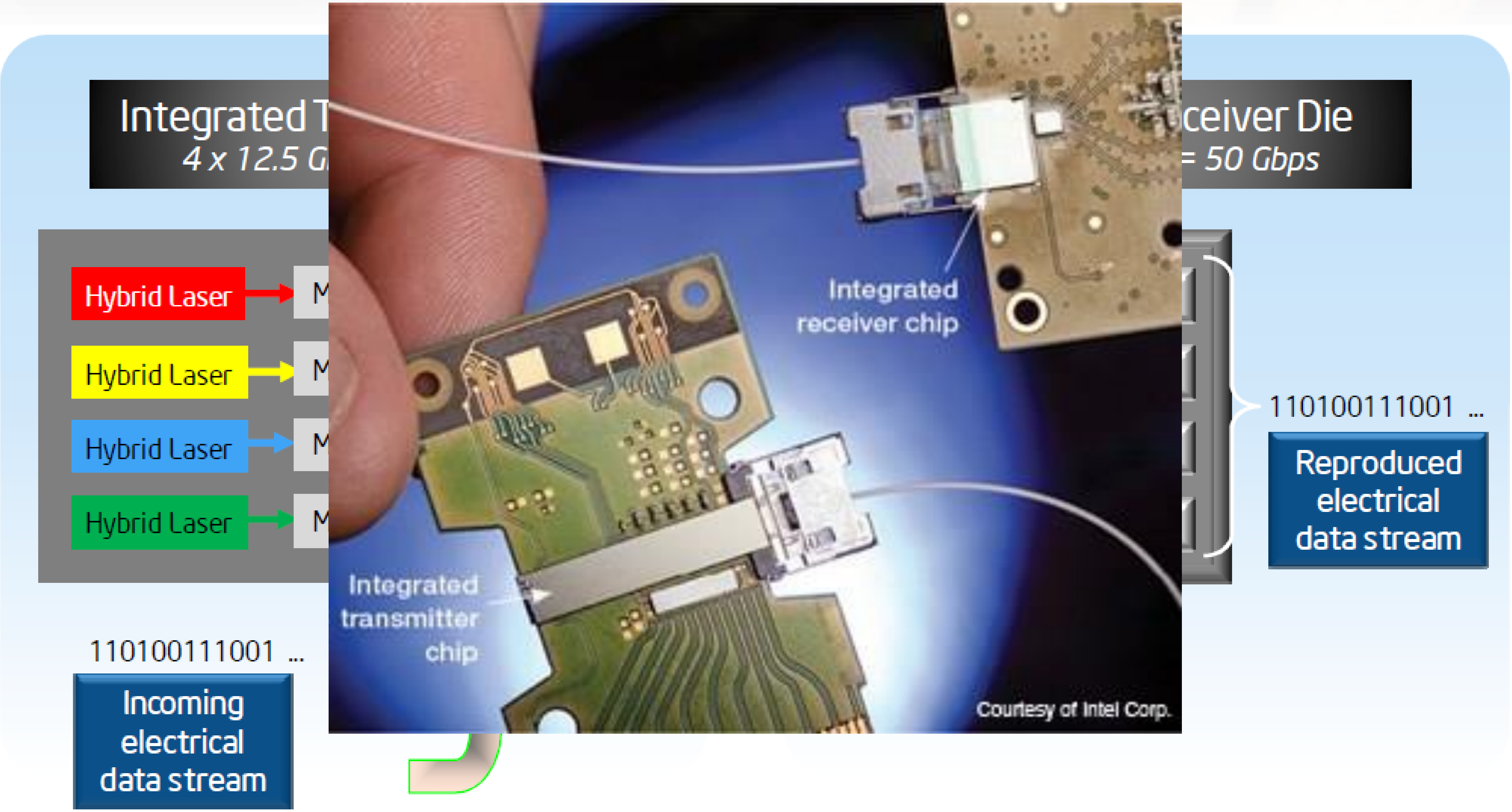
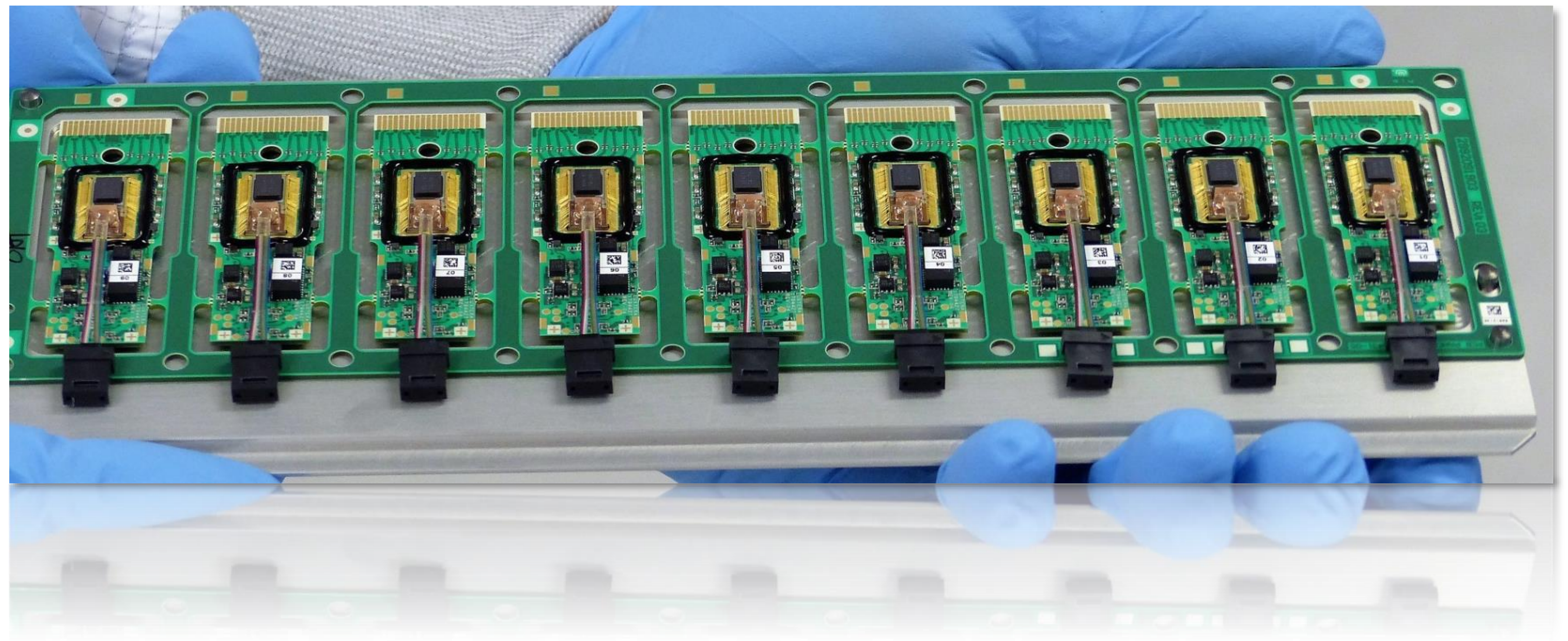


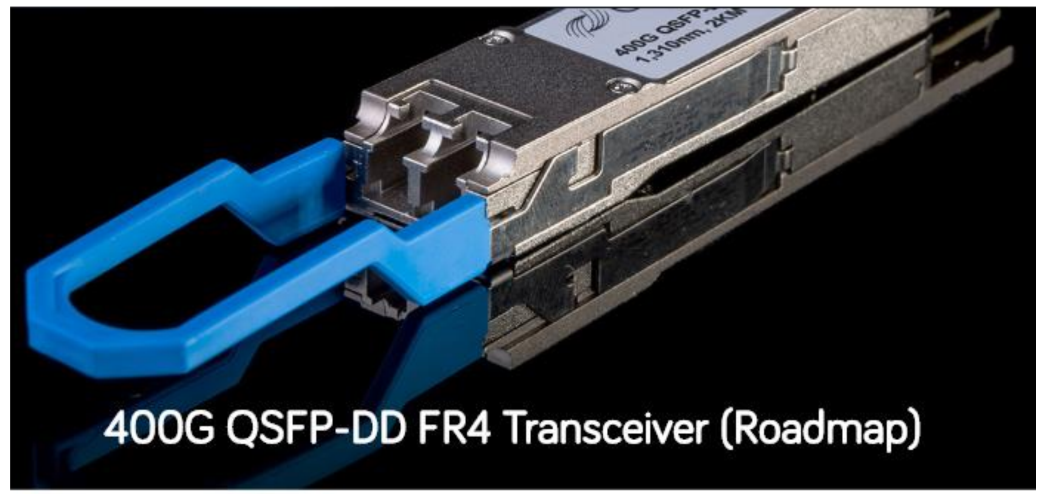
Datacom (2020) – integrated SFP modules

intel 100 Gb/s

LUXTERA CISCO 100 Gb/s

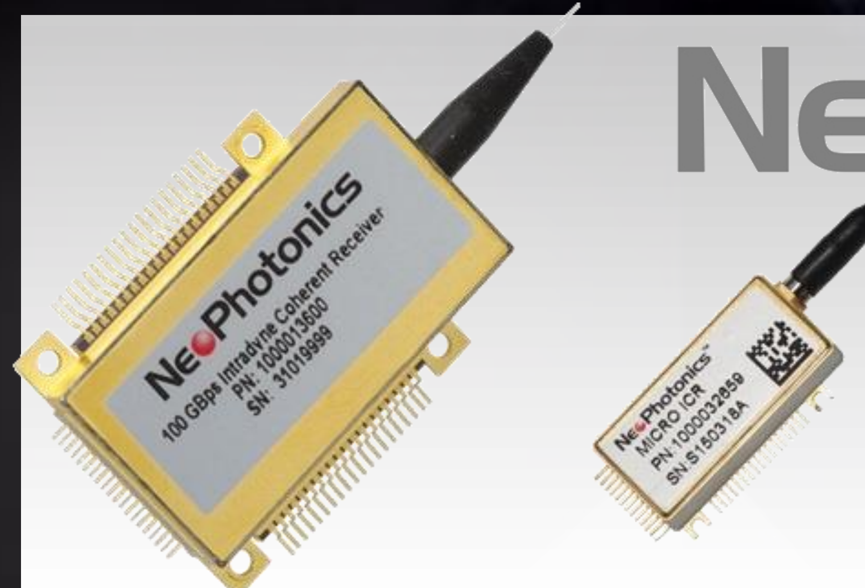


ColorChip SystemOnGlass™ 100-400 Gb/s

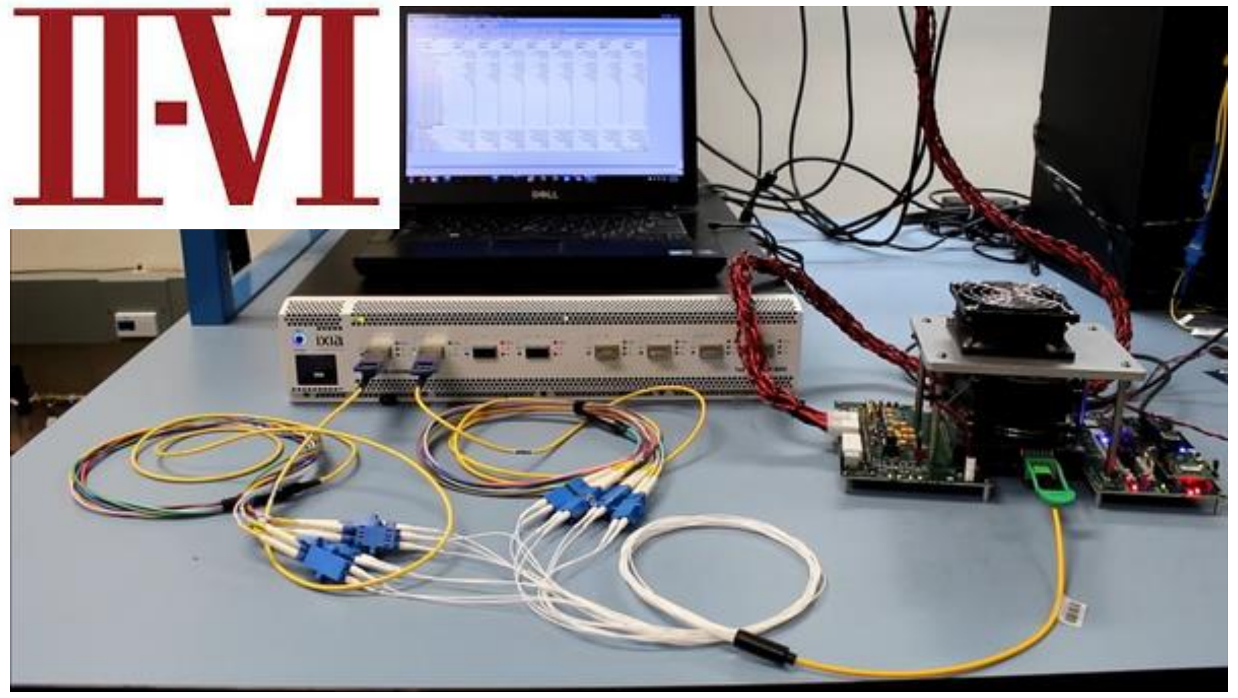


Telecom and datacom integrated photonic market

NeoPhotonics



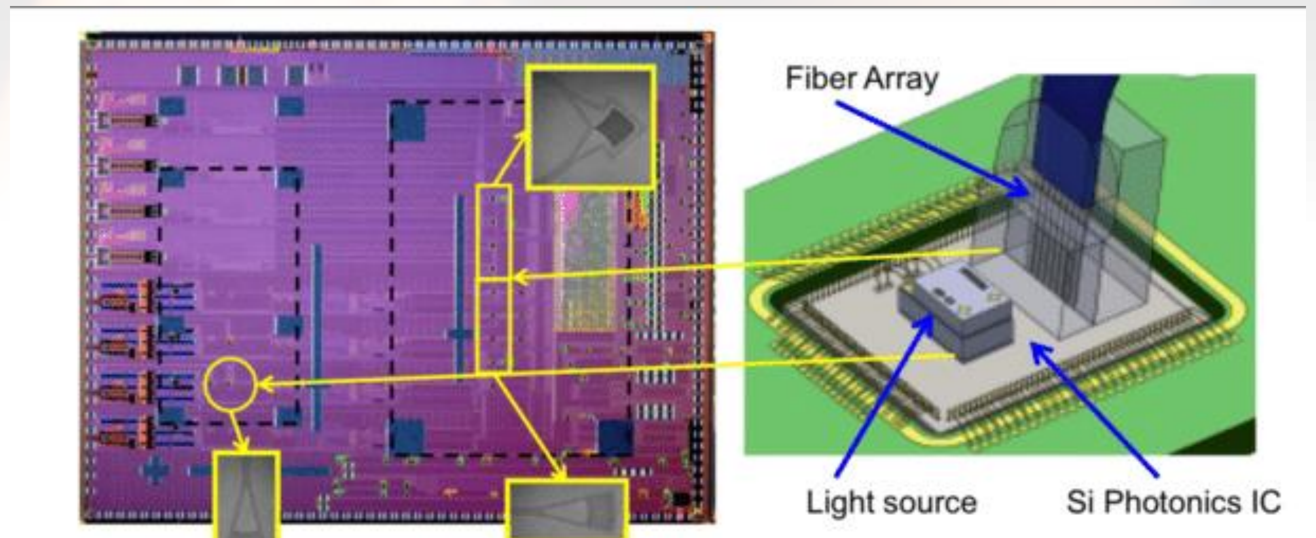
II-VI



400/800G Transceivers for NG
25.6/51.2T Datacenter Switches

ACACIA
COMMUNICATIONS, INC.

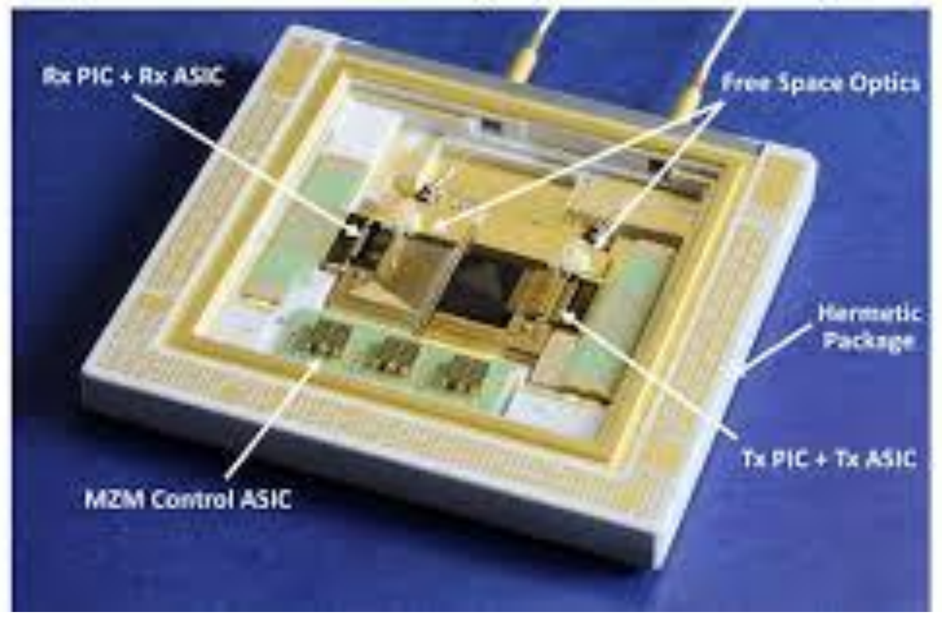
LUXTERA
FIBER TO THE CHIP



Transceivers 10G

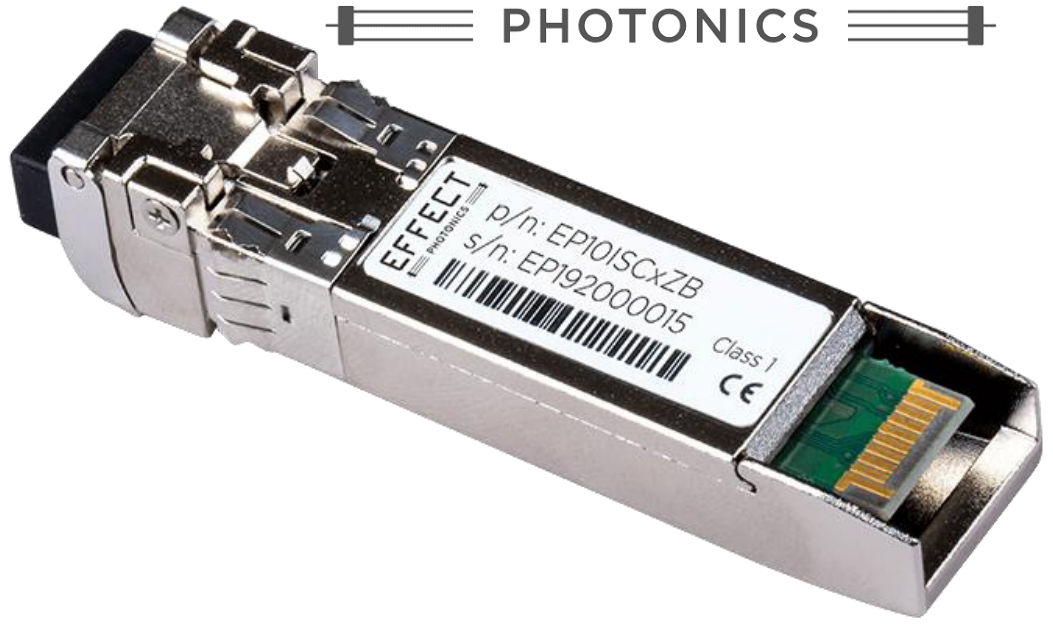
infinera

1.2 Tb/s Coherent Transceiver Module
(6 channels x 200 Gb/s, PM 16-QAM)



CFP2 and
QSFP-DD

EFFECT
PHOTONICS



HISILICON
OPTOELECTRONICS

ColorChip
SystemOnGlass™

VIGO PHOTONICS

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of Technology

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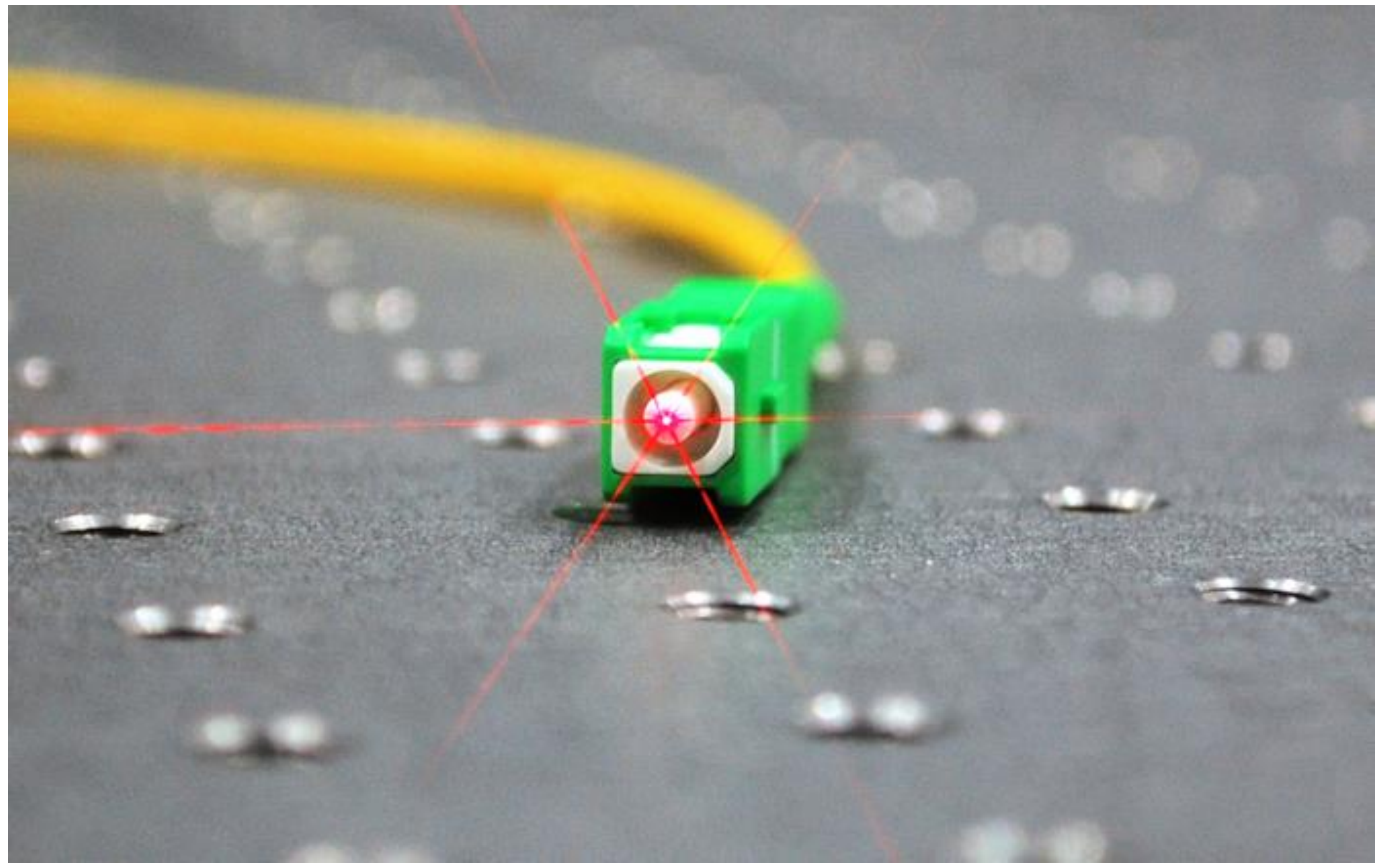
- data communication (data centers)
- others



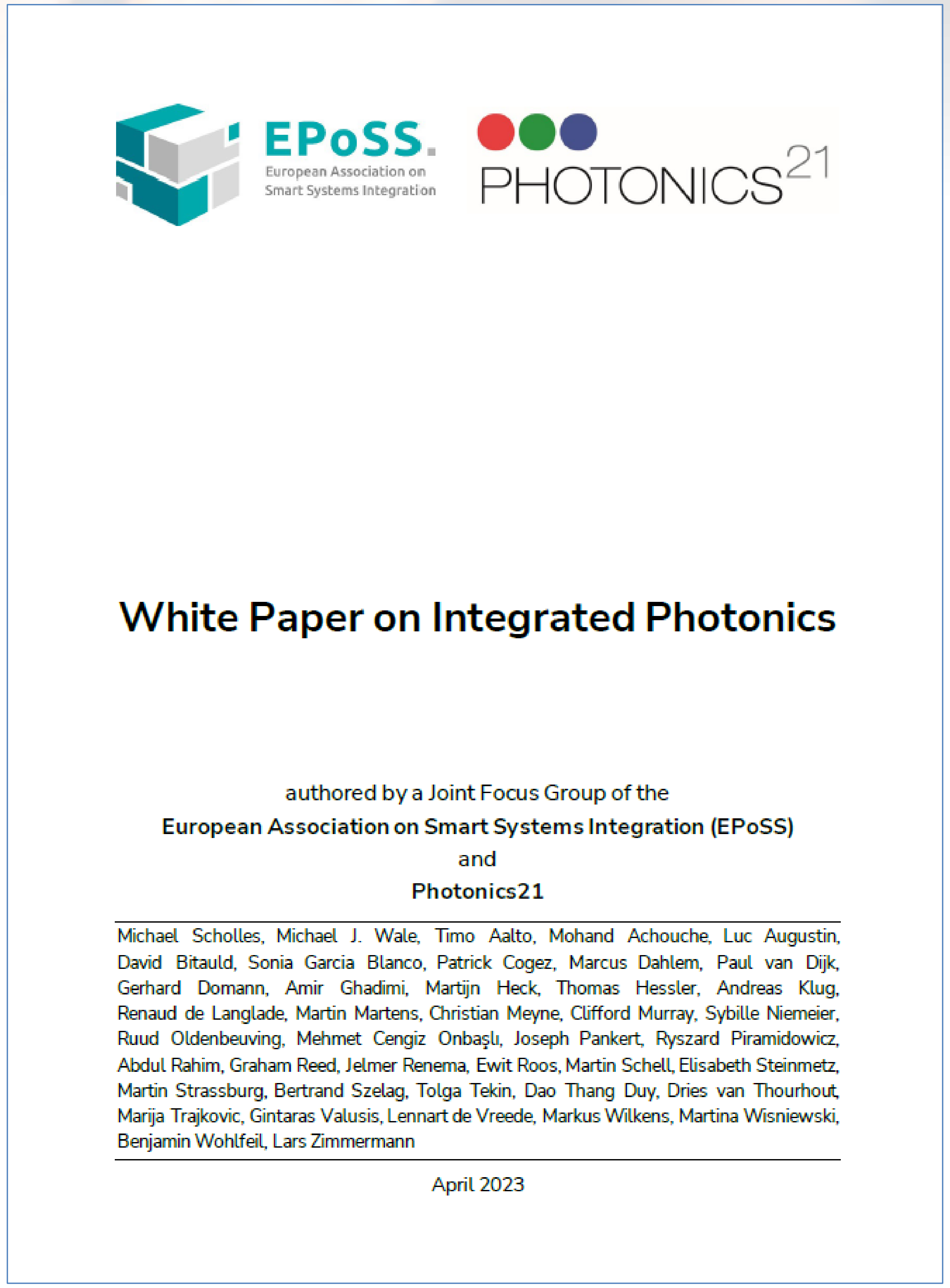
Applications

- **High-Performance Computing**
  in-system optical interconnects, neuromorphic and quantum computing

- **Agrifood and Natural Resources**
  various types of PIC-based sensors for detecting potentially harmful molecules and substances

- **Safety and Security**
  monitoring of critical infrastructure and civil infrastructure objects, detection of explosives, chemical weapons, etc.

- **Industrial Sensing and Automation**
  sensors and imaging systems monitoring gases, liquids and solid materials, measuring thicknesses of thin films, shapes and roughness of surfaces, distances, speeds, accelerations, temperatures, pressures etc.


EPoSS. European Association on Smart Systems Integration
PHOTONICS21

White Paper on Integrated Photonics

authored by a Joint Focus Group of the
European Association on Smart Systems Integration (EPoSS)
and
Photonics21

Michael Scholles, Michael J. Wale, Timo Aalto, Mohand Achouche, Luc Augustin, David Bitauld, Sonia Garcia Blanco, Patrick Cogez, Marcus Dahlem, Paul van Dijk, Gerhard Domann, Amir Ghadimi, Martijn Heck, Thomas Hessler, Andreas Klug, Renaud de Langlade, Martin Martens, Christian Meyne, Clifford Murray, Sybille Niemeier, Ruud Oldenbeuving, Mehmet Cengiz Onbaşlı, Joseph Pankert, Ryszard Piramidowicz, Abdul Rahim, Graham Reed, Jelmer Renema, Ewit Roos, Martin Schell, Elisabeth Steinmetz, Martin Strassburg, Bertrand Szelag, Tolga Tekin, Dao Thang Duy, Dries van Thourhout, Marija Trajkovic, Gintaras Valusis, Lennart de Vreede, Markus Wilkens, Martina Wisniewski, Benjamin Wohlfeil, Lars Zimmermann

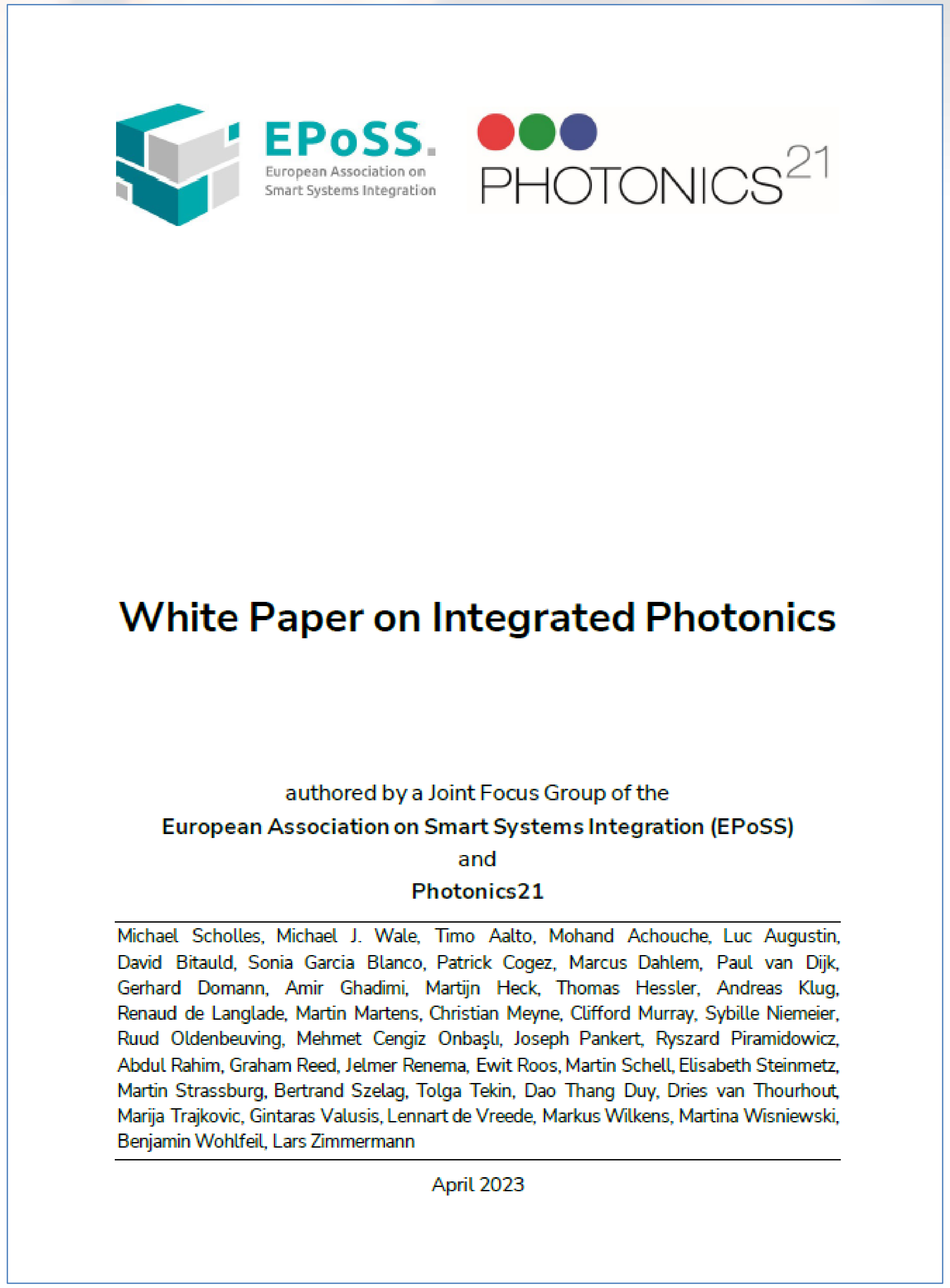
April 2023

Applications

- **Health and Wellbeing**
  medical optical imaging (e.g., highly integrated endoscopes), photonic biosensors, continuous monitoring of patients' health status to detect diseases at an early stage or to continuously monitor the progression of illnesses outside a medical environment

- **Mobility and Space**
  with future mobility concepts that require advanced environmental sensing, in particular, components for LiDAR systems, communication systems, etc.

- **Consumer electronics**
  digital health monitoring, wearable systems (smartbends, smartwatches, smartphones etc. equipped with PIC sensors)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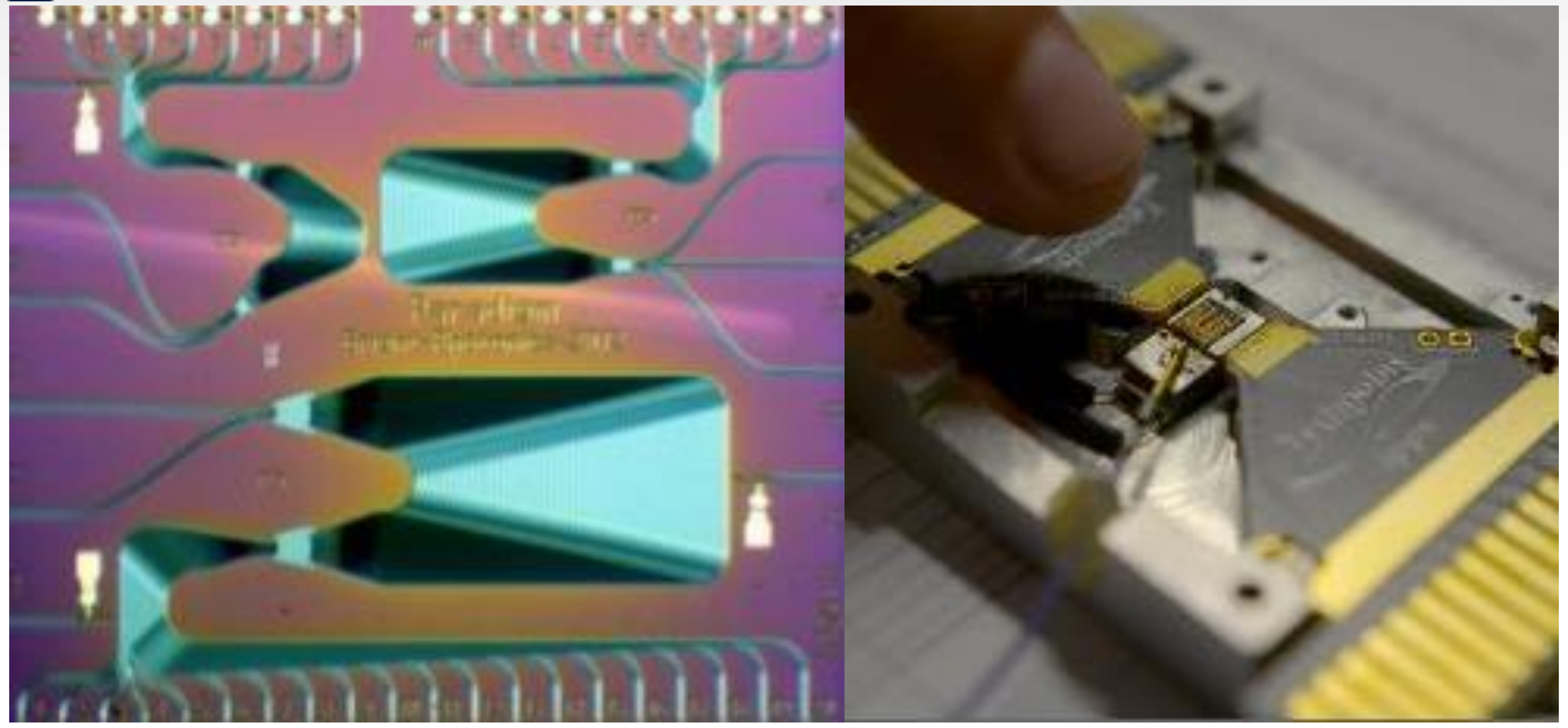
April 2023

Rising field – sensing

PHOTONFIRST

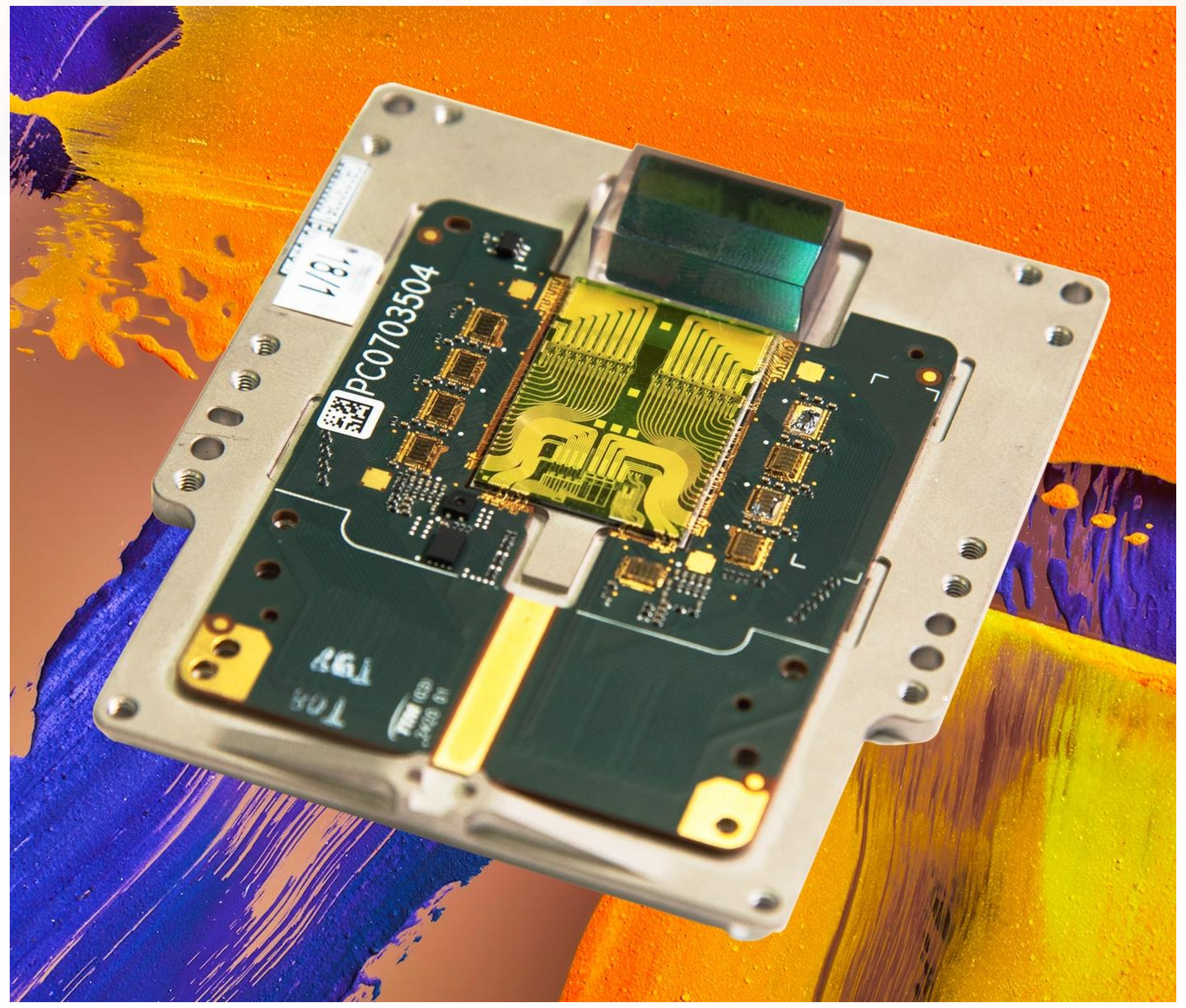


optical interrogators

Genalyte

SARS-CoV-2 detection

mobileye
An Intel Company

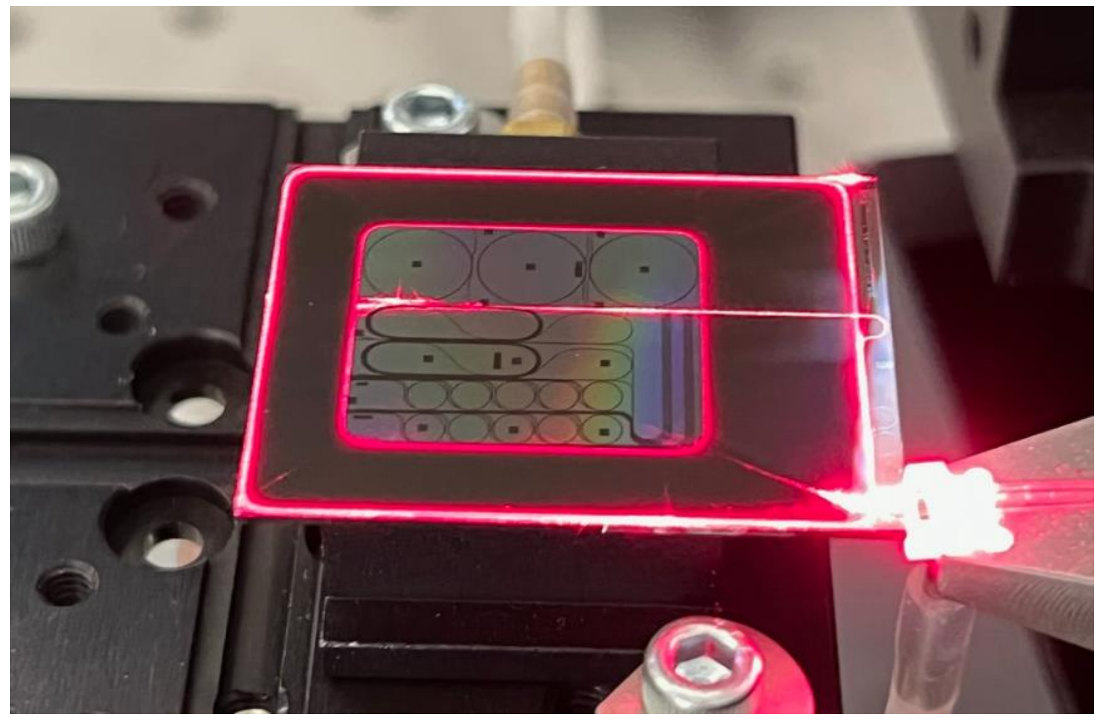


Lidar System-On-Chip

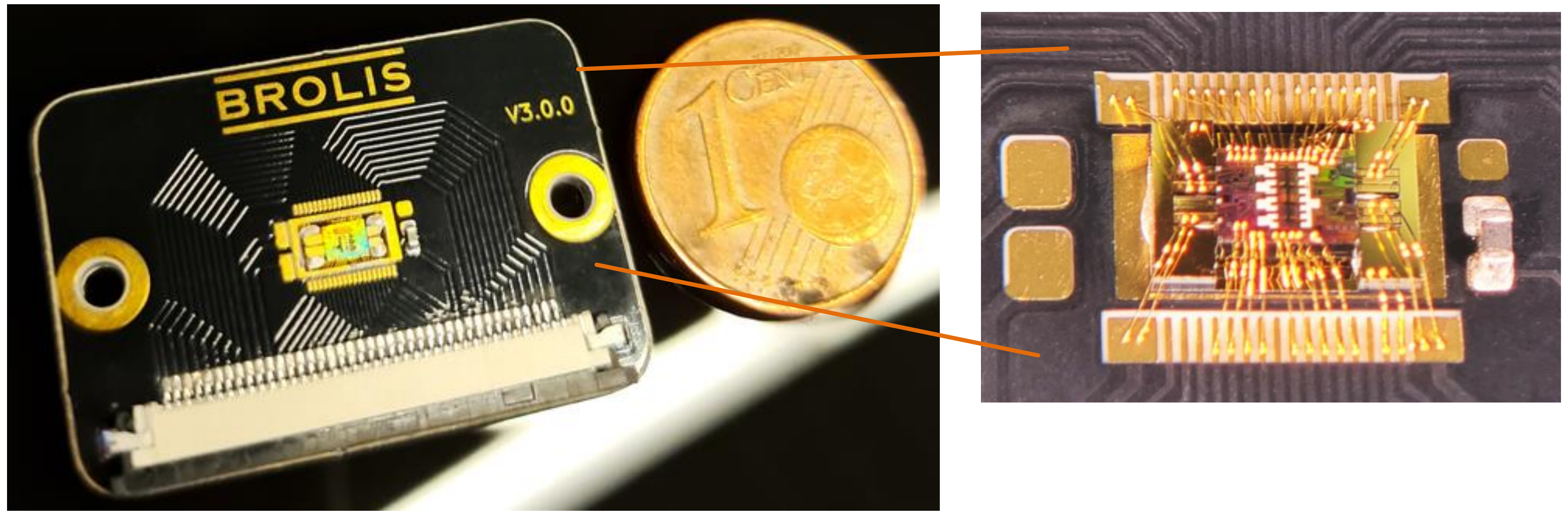
LioniX INTERNATIONAL

biosensor-array module
for drug screening

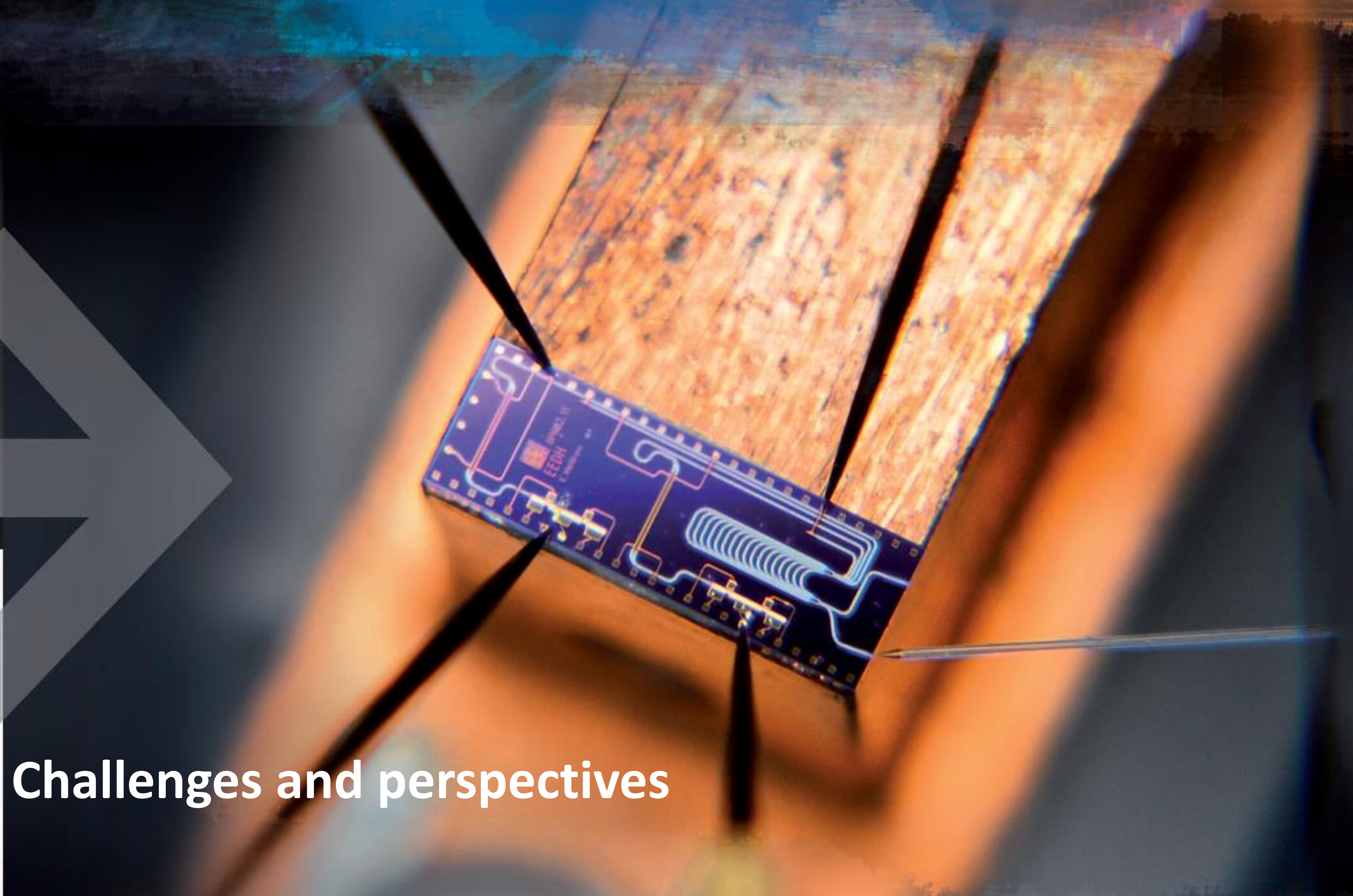
ANELLO



SIPHOG™ – optical gyro



spectrometer-on-a-chip



Challenges and perspectives

Challenges and perspectives

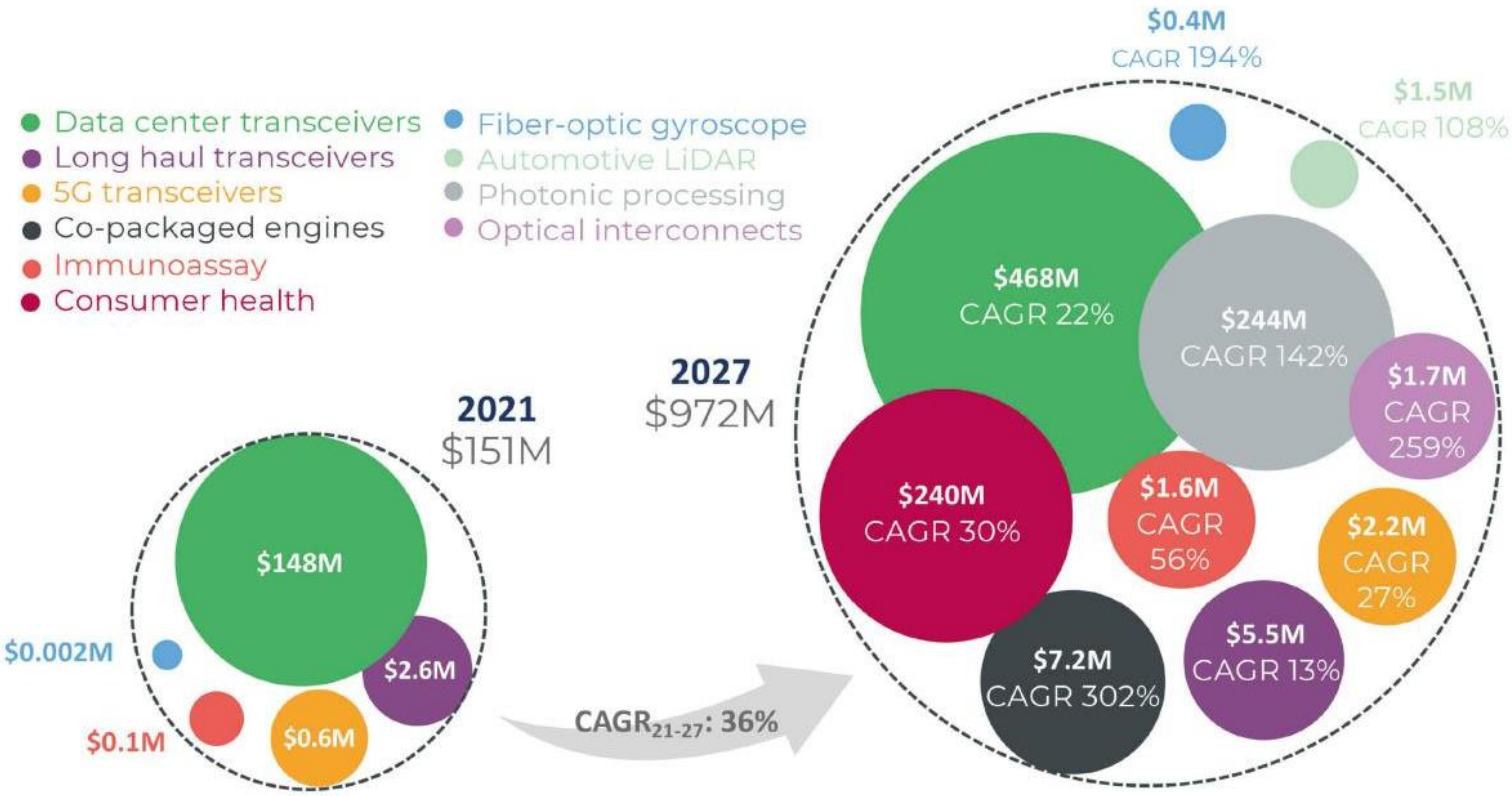
Integrated photonics is among the most important technologies of the information society, already revolutionizing the telecom and datacom market.

Major challenges:

- **scaling-up manufacturing resources,**
- **mass-scale generic packaging,**
- **electronic-photonic integration,**
- **new application fields and new markets!**

Challenges and perspectives

Silicon photonic 2021-2027 market forecast



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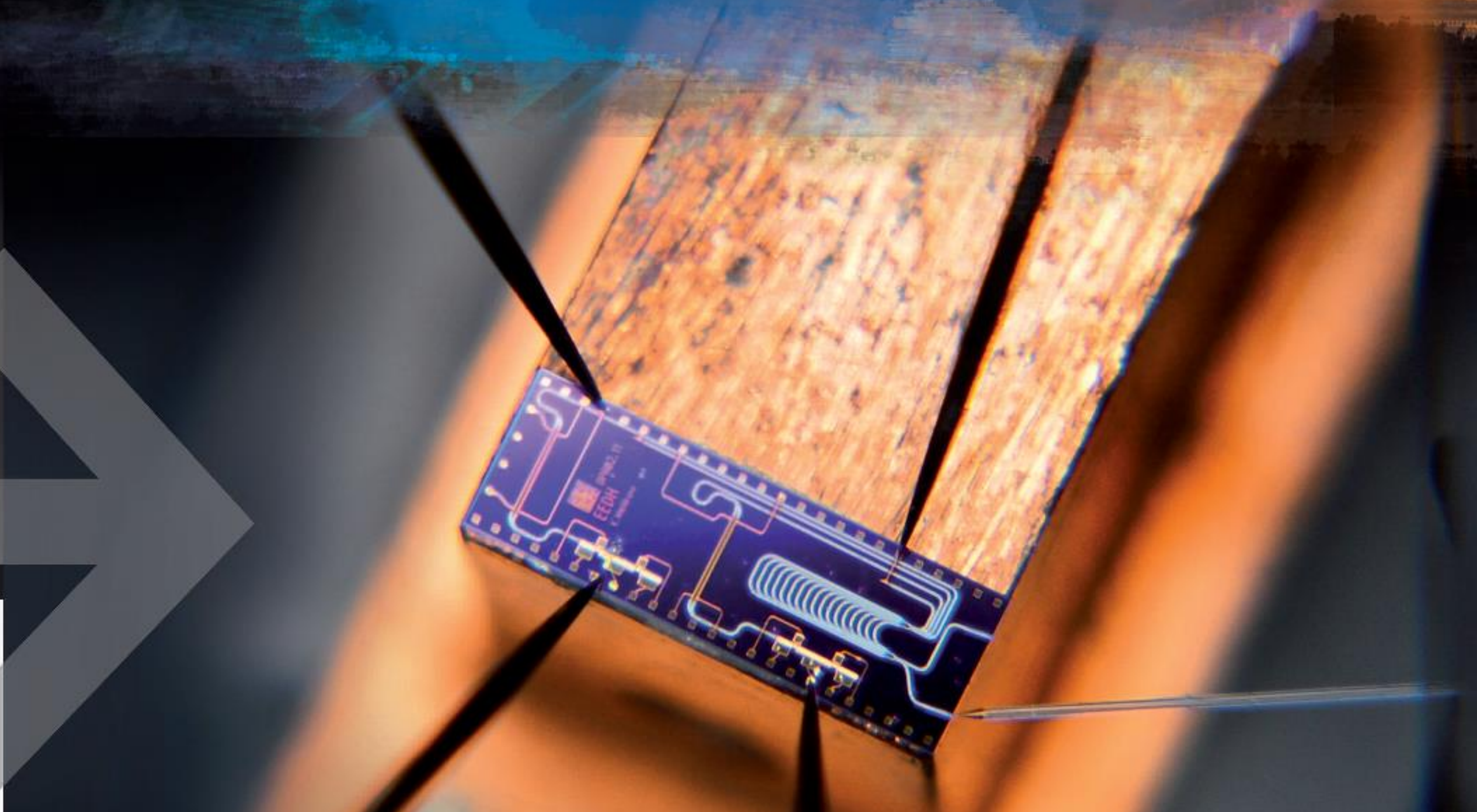
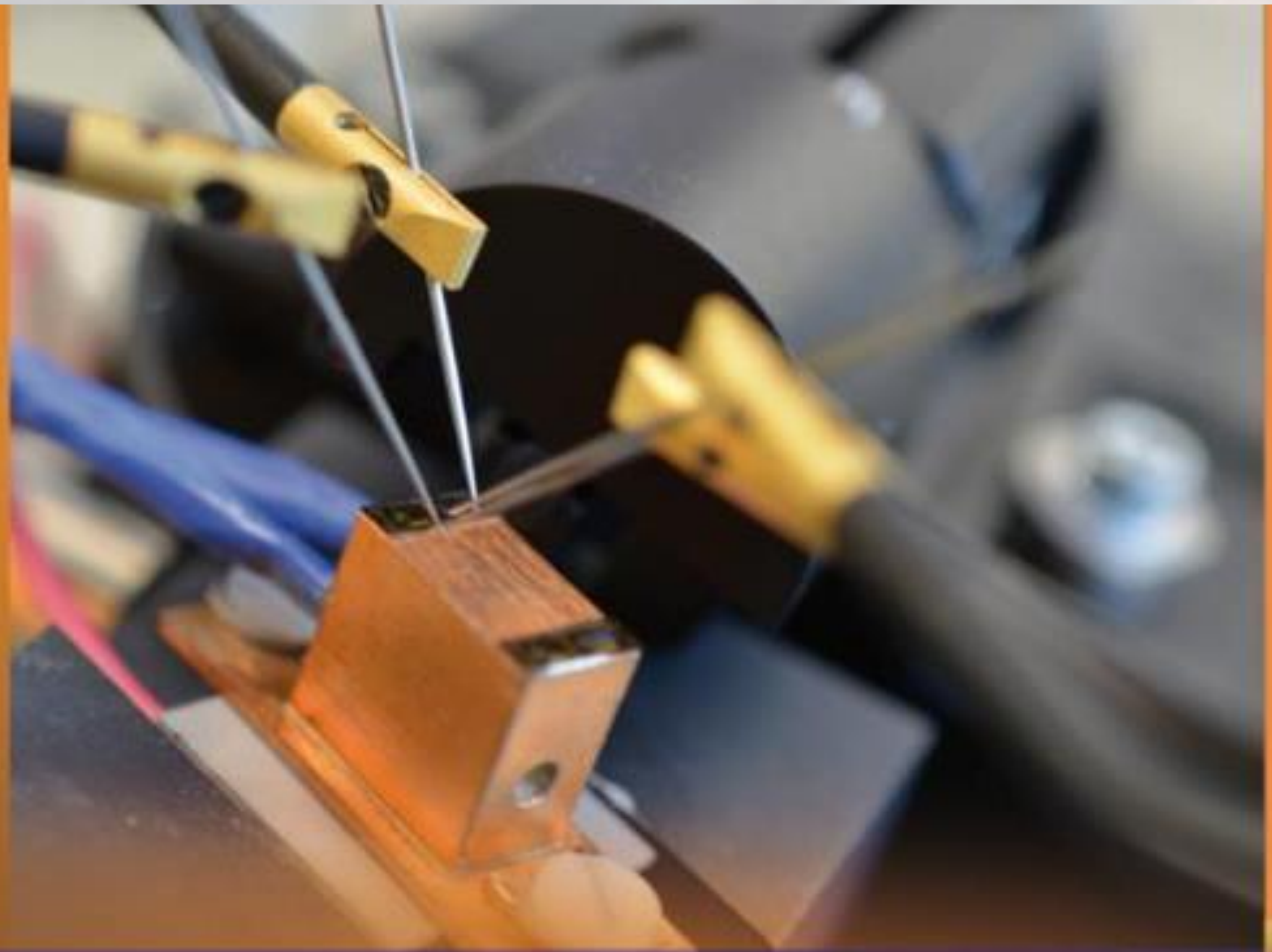
Extension of spectral range (towards VIS and MIR) is a must!



POLISH PERSPECTIVE

Integrated photonics @ WUT – design and technology

Integrated photonics @ WUT



- established in 2011
- first ASPIC designed in 2012
- characterization lab finalized in 2014
- first ASPIC characterized in 2013
- first technological trials in 2019 (CEZAMAT WUT)
- first Polish Design House LightHouse established in 2022

VIGO PHOTONICS

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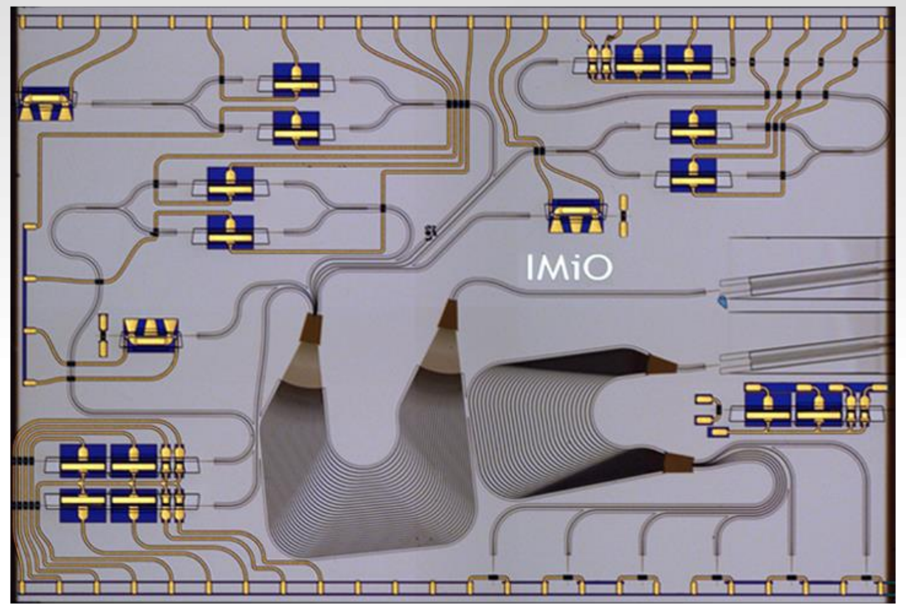
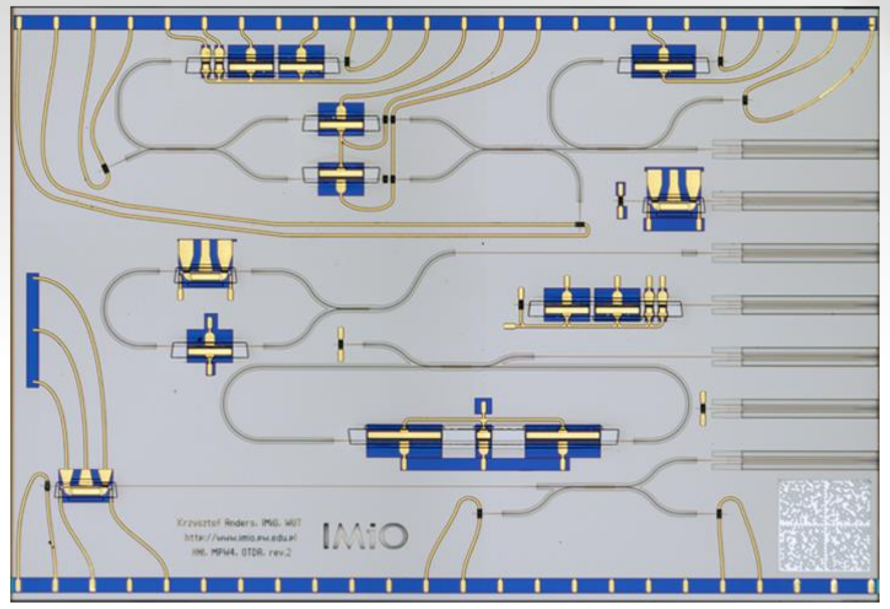
Eastern Europe Design Hub & LightHouse

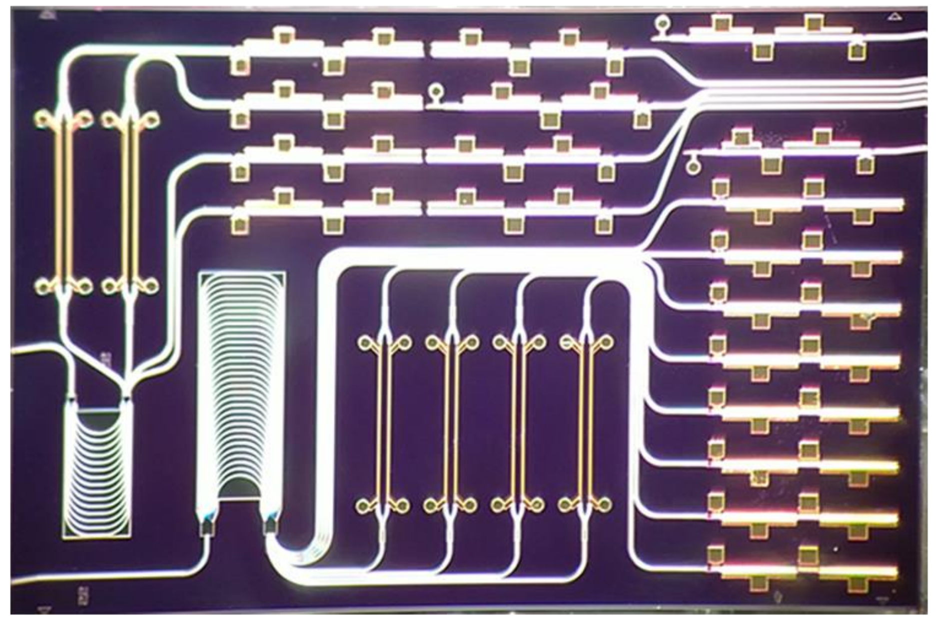
120+ ASPIC circuits designed by EEDH, manufactured by generic foundries

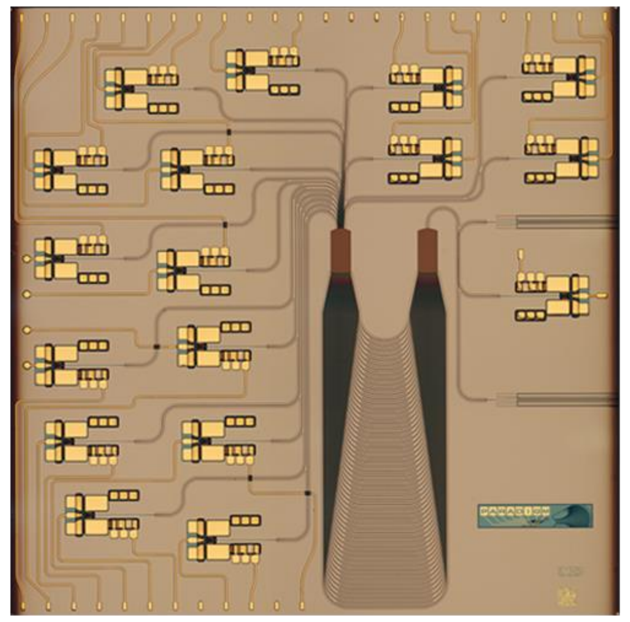


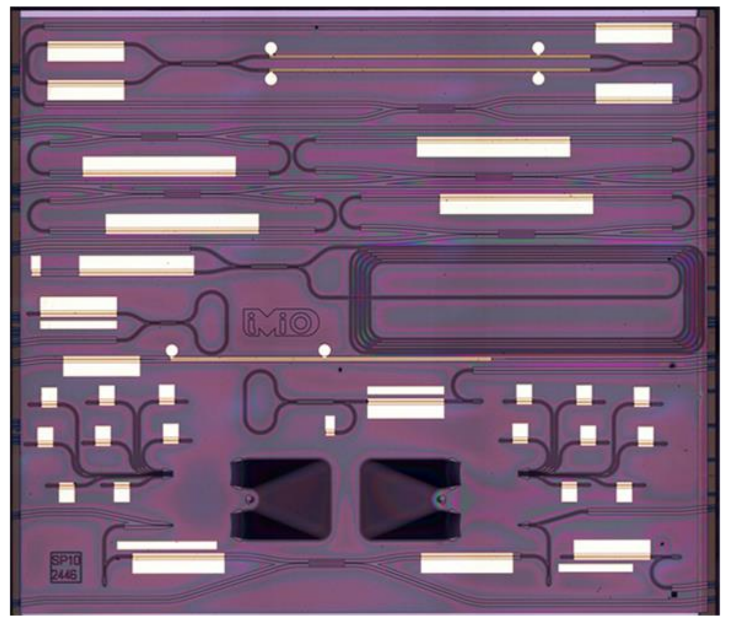
Multi-channel transceiver for free space optics

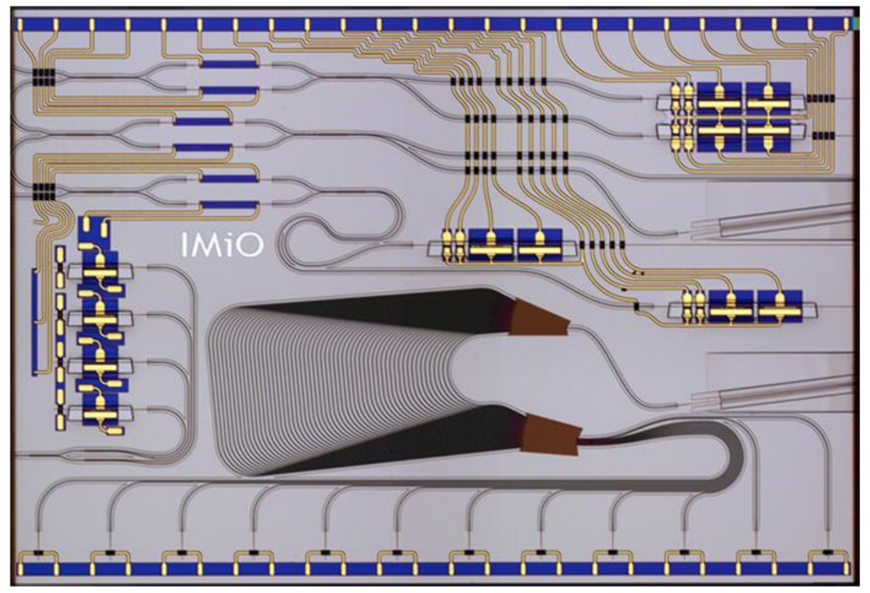

Optical time domain reflectometer


Multi-wavelength laser

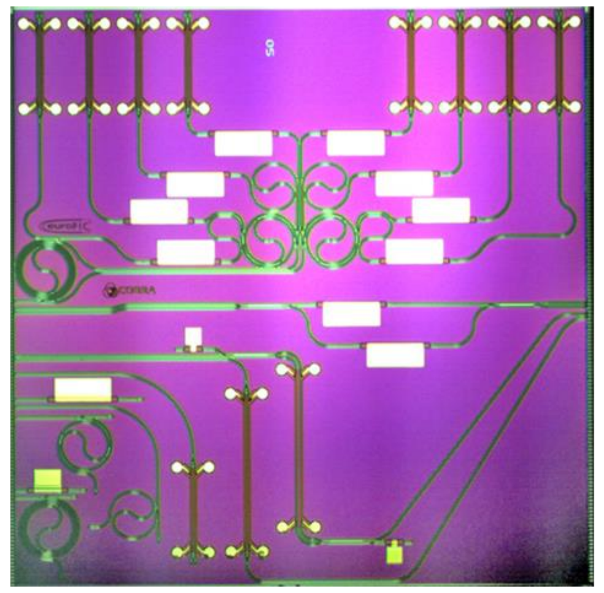

Multi-channel transmitter for FTTH networks

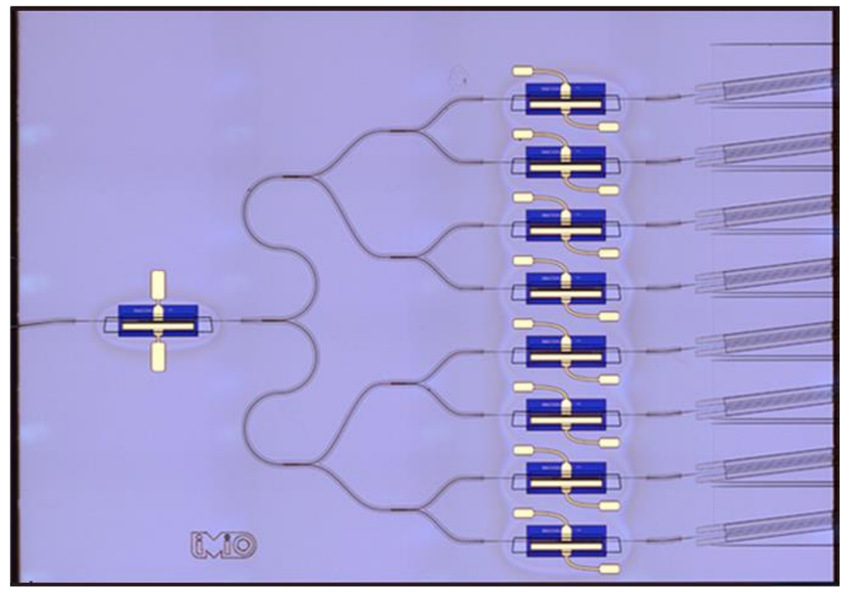

Spectrometer for FBG sensor interrogator

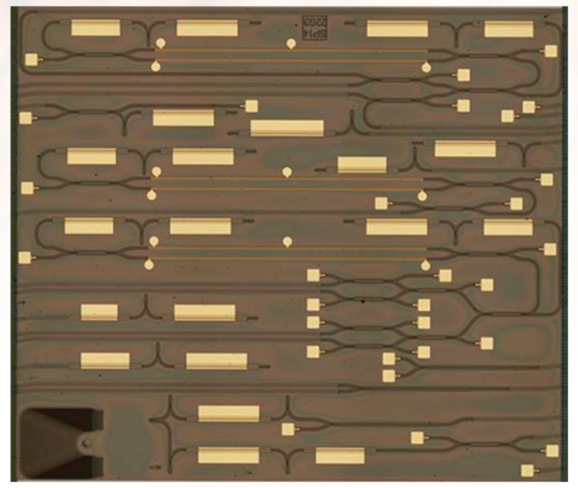

Discretely tunable laser

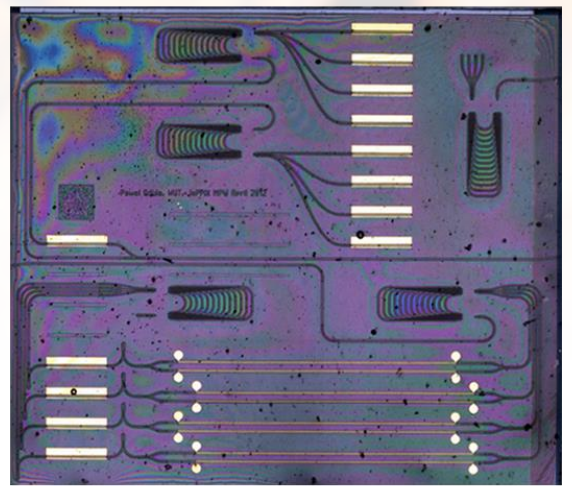


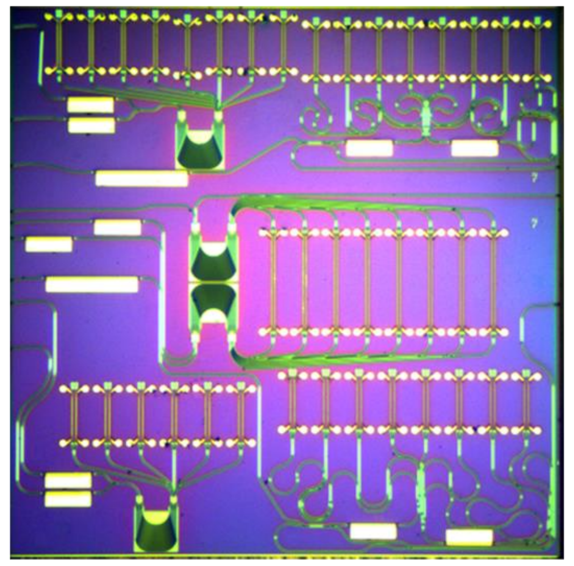
FBG interrogator unit

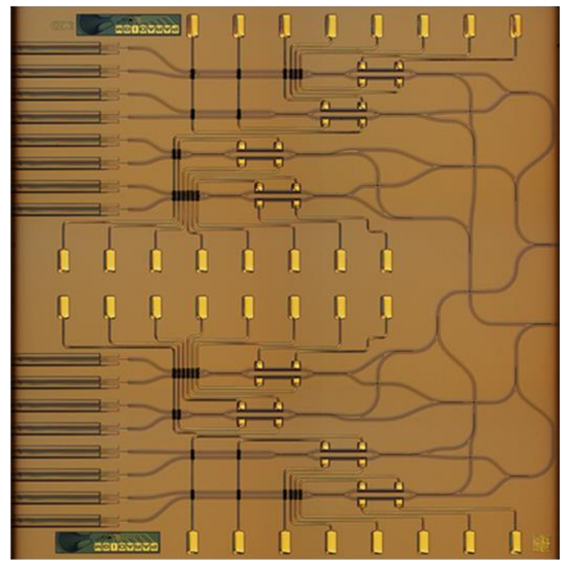

Optical time division multiplexer

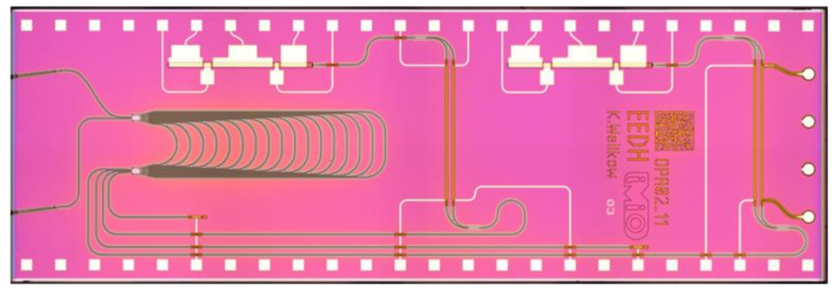

Lossless power splitter

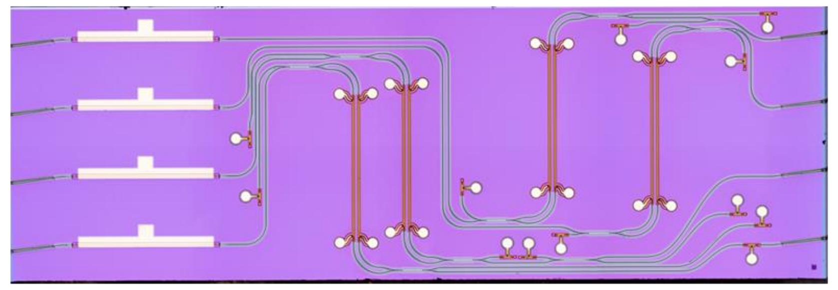

Multi-channel optical time domain reflectometer


Multi-channel transmitter for FTTH networks


Photonic data readout units


2x8 optical switch for fiber-optic access systems


Photonic transceiver for metrology applications


Photonic integrated transceiver for data readout units

SMART PHOTONICS
Independent InP Foundry

COBRA (Materials, Devices, Systems)

OCLARO

Fraunhofer Heinrich-Hertz-Institut

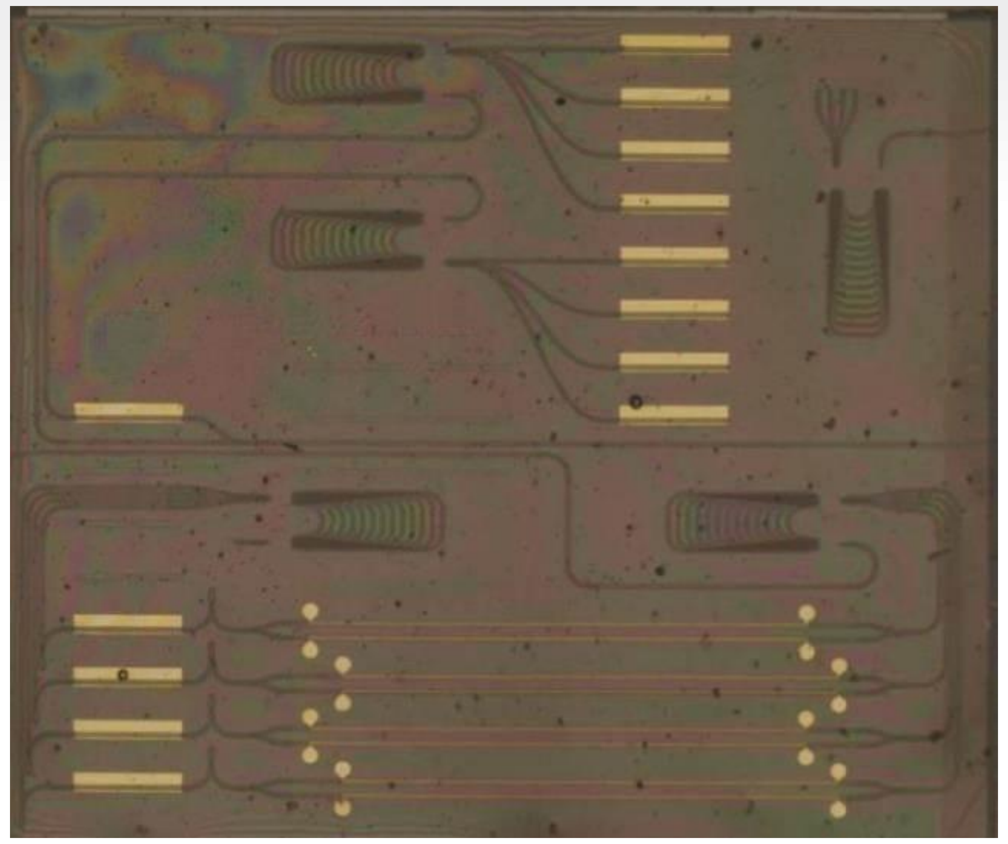
VIGO PHOTONICS

Warsaw University of Technology

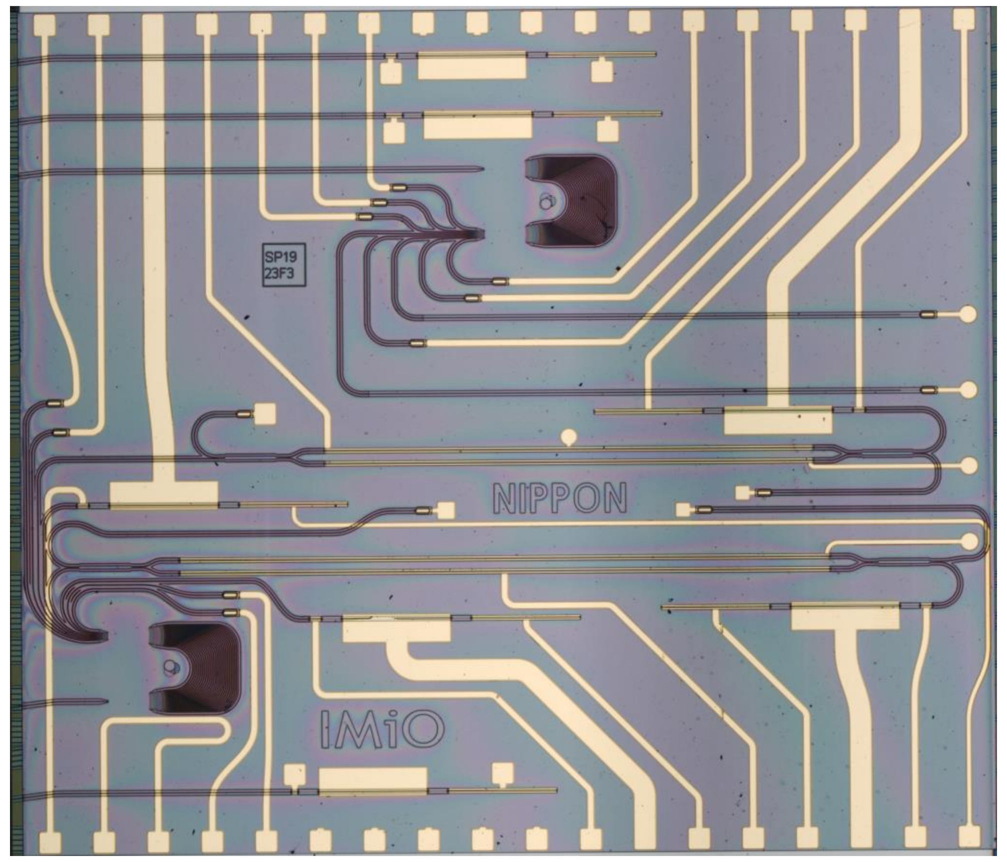
Multi-wavelength transmitters for telecom and datacom

Four generations of ASPICs designed, developed and tested (TRL6)

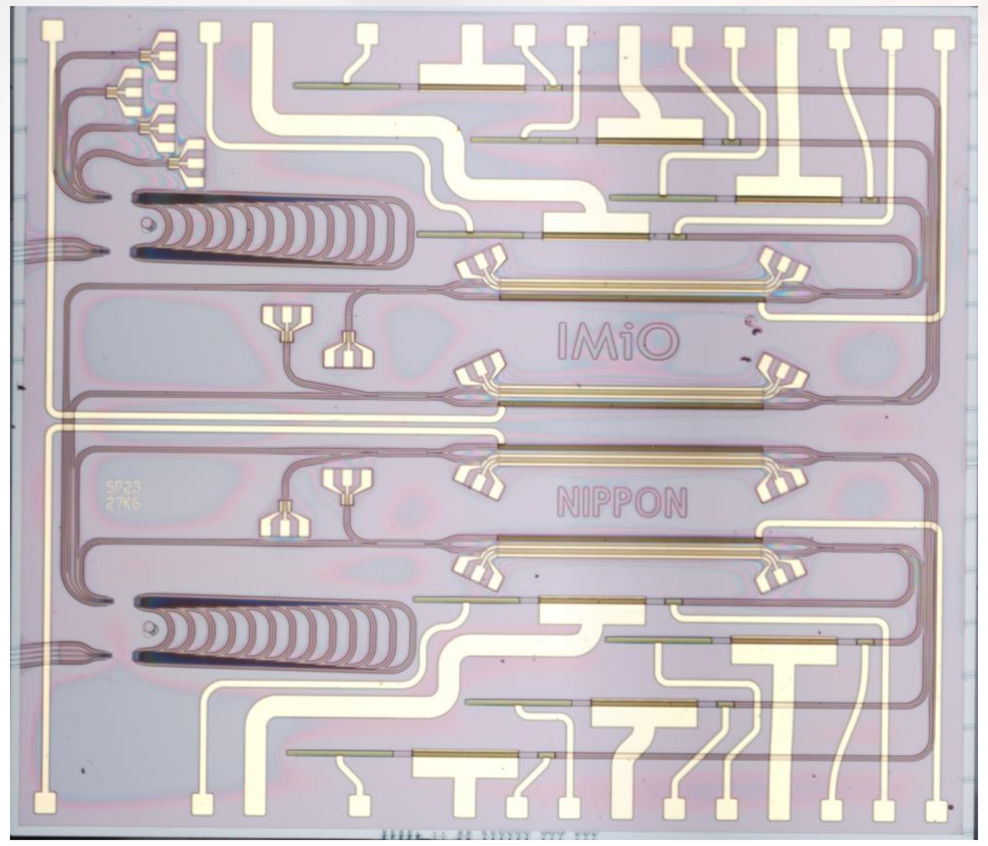
1st

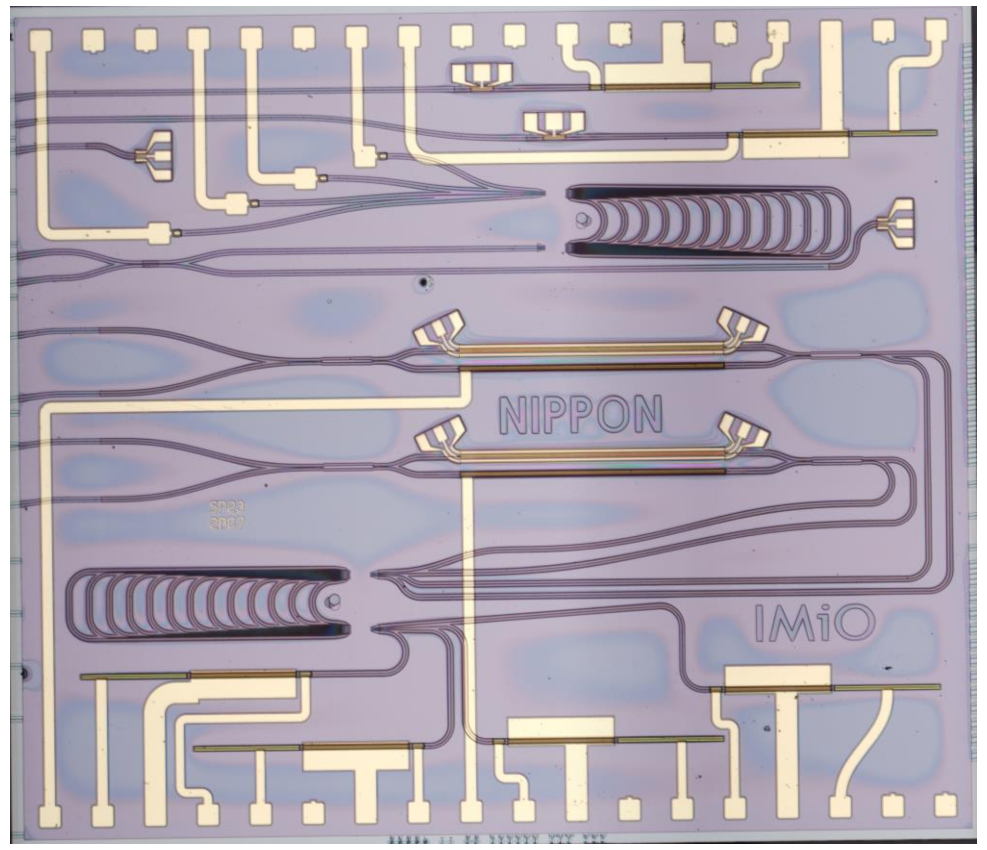


2nd

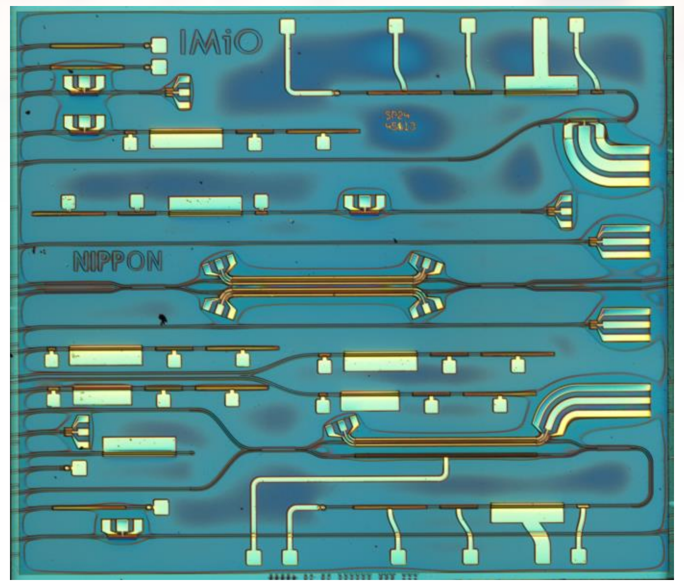


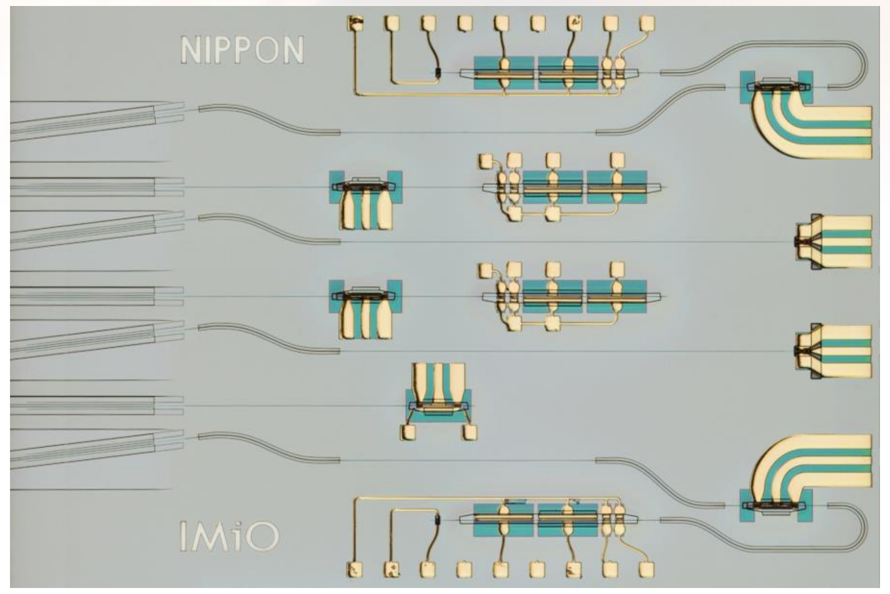
3rd

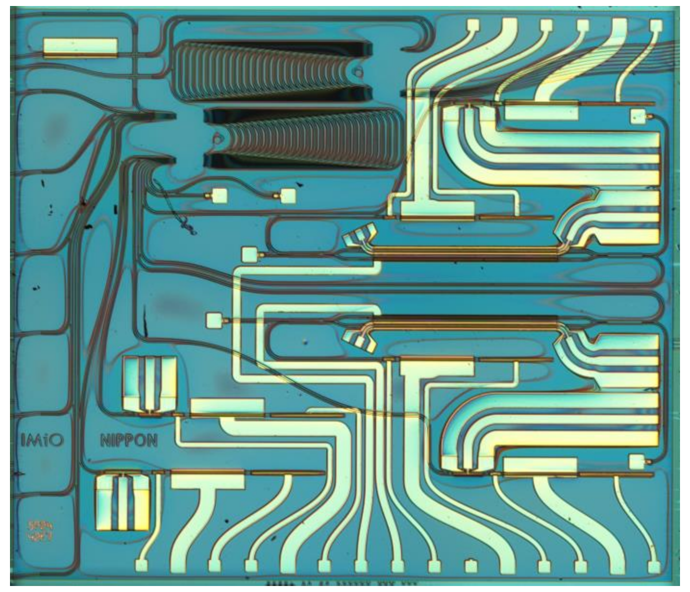


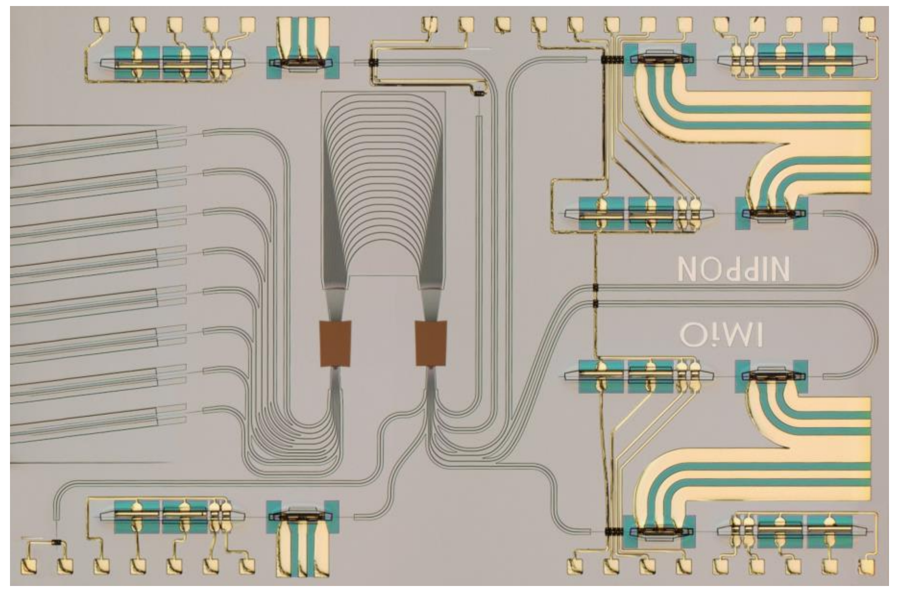


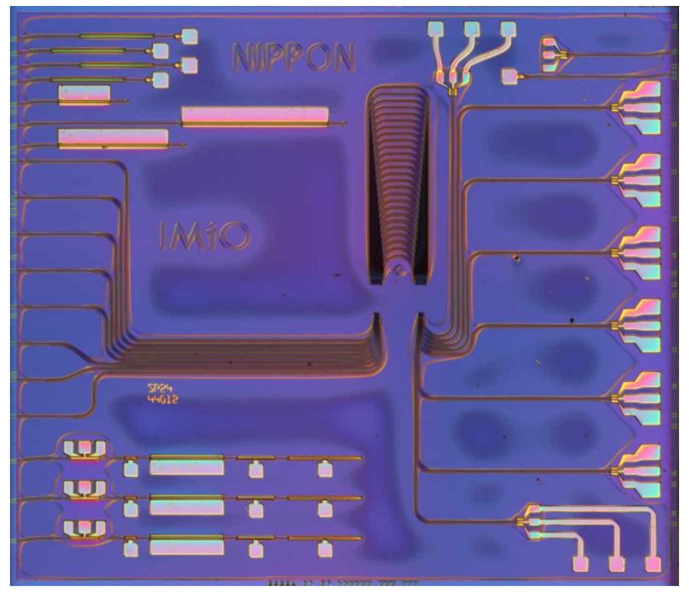
4th

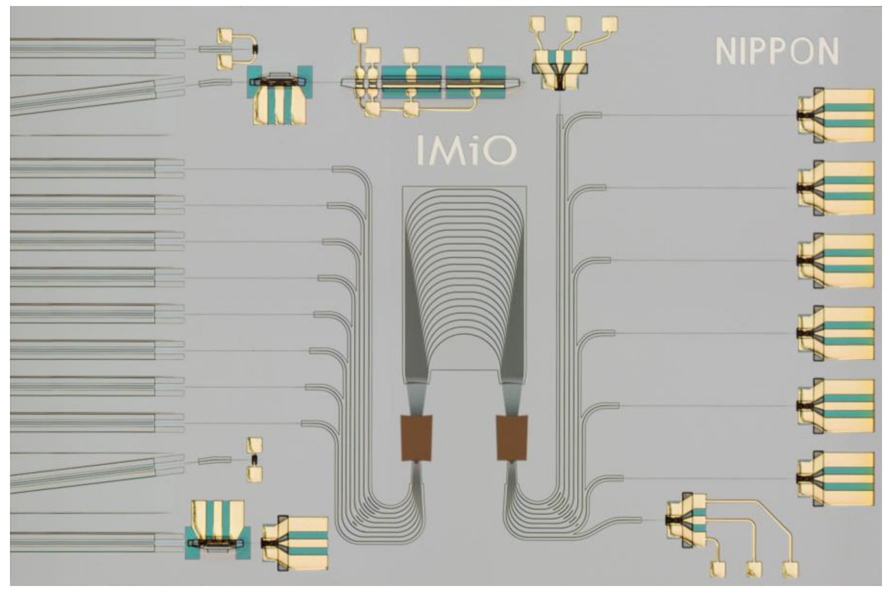










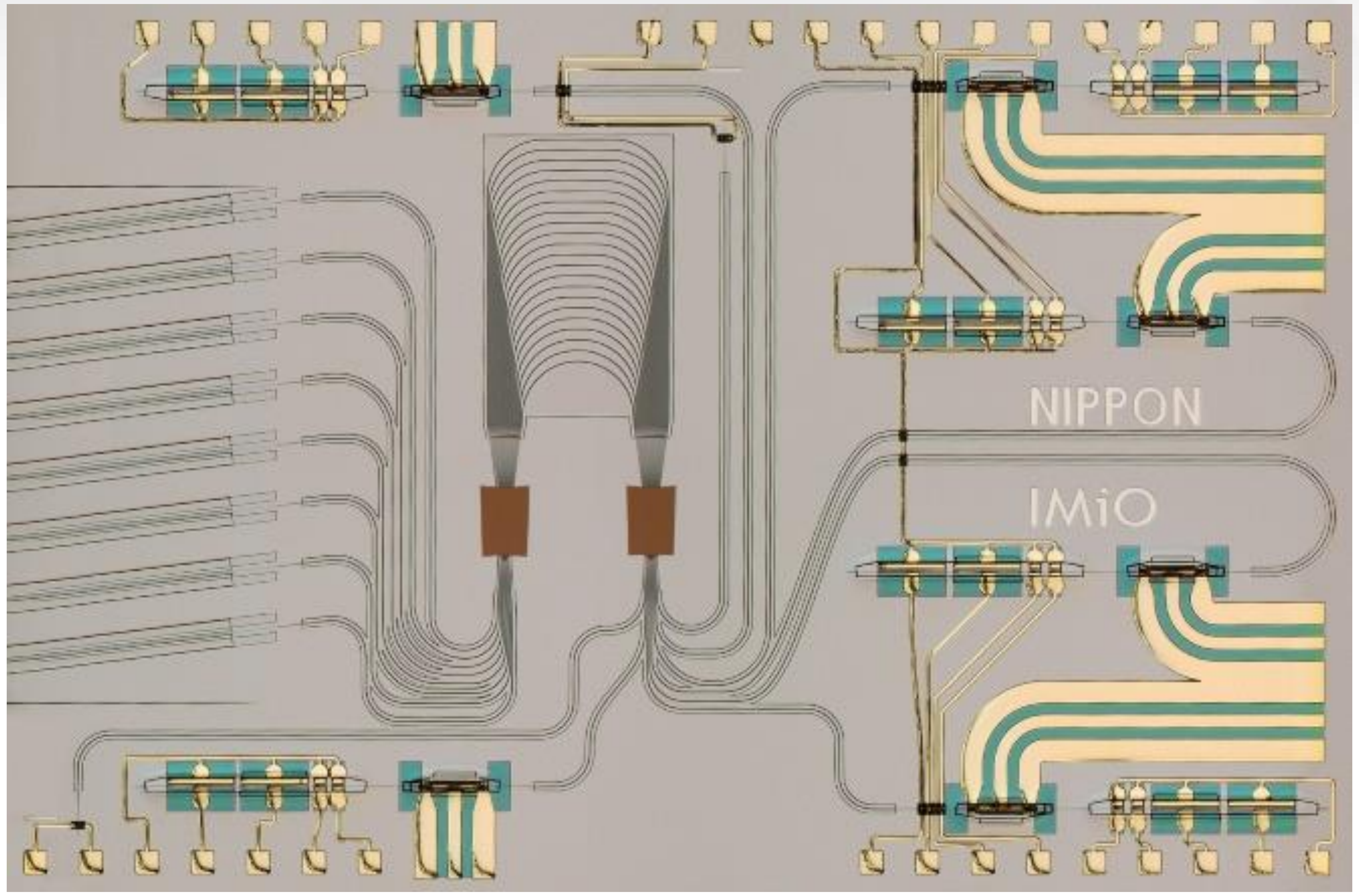


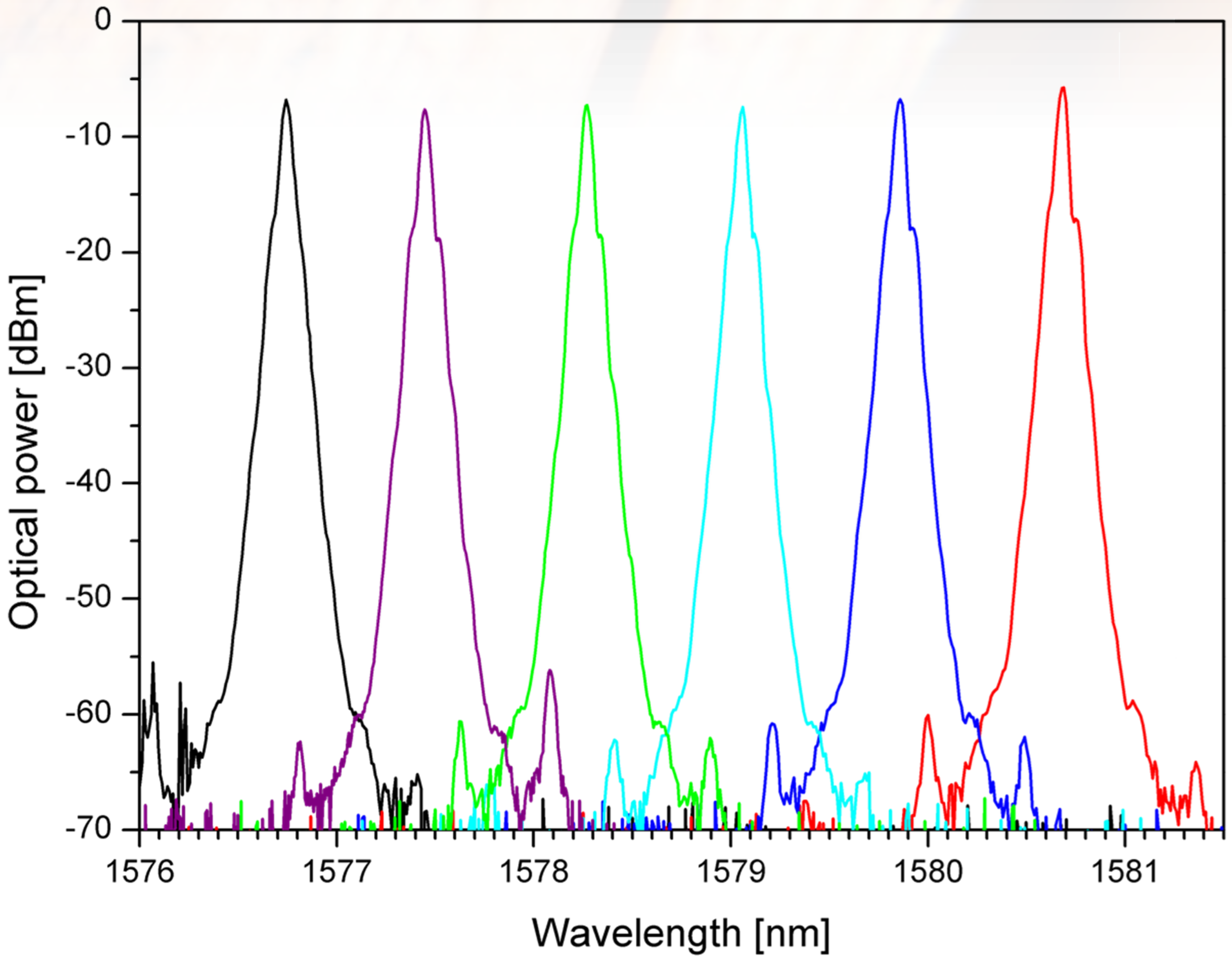
VIGO PHOTONICS

Warsaw University of Technology

Multi-wavelength transmitters for telecom and datacom

Four generations of ASPICs designed, developed and tested (TRL6)

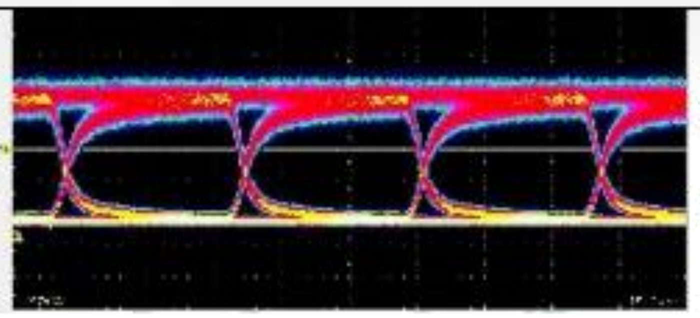
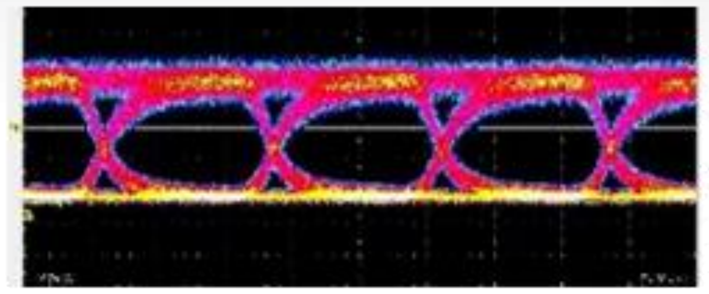
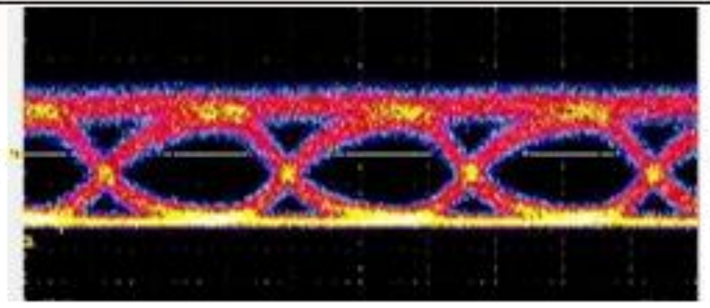
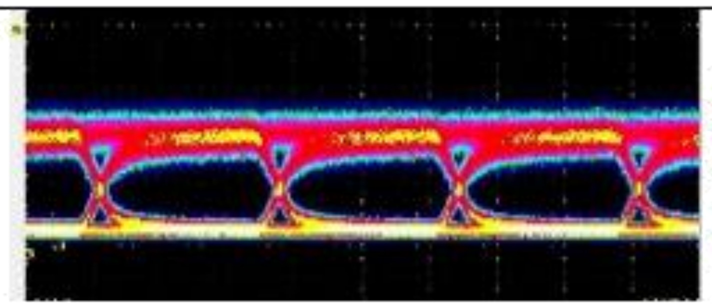
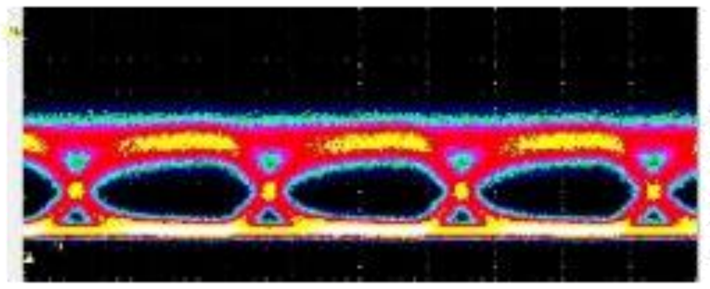
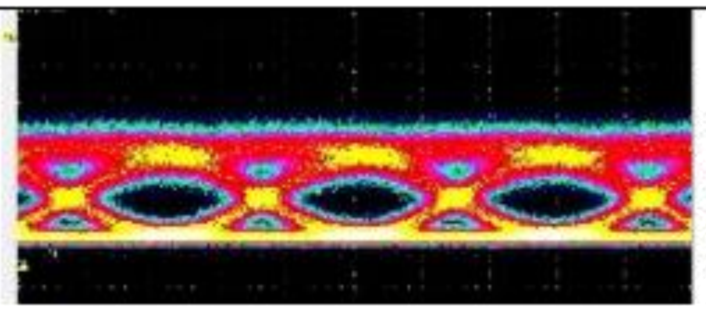


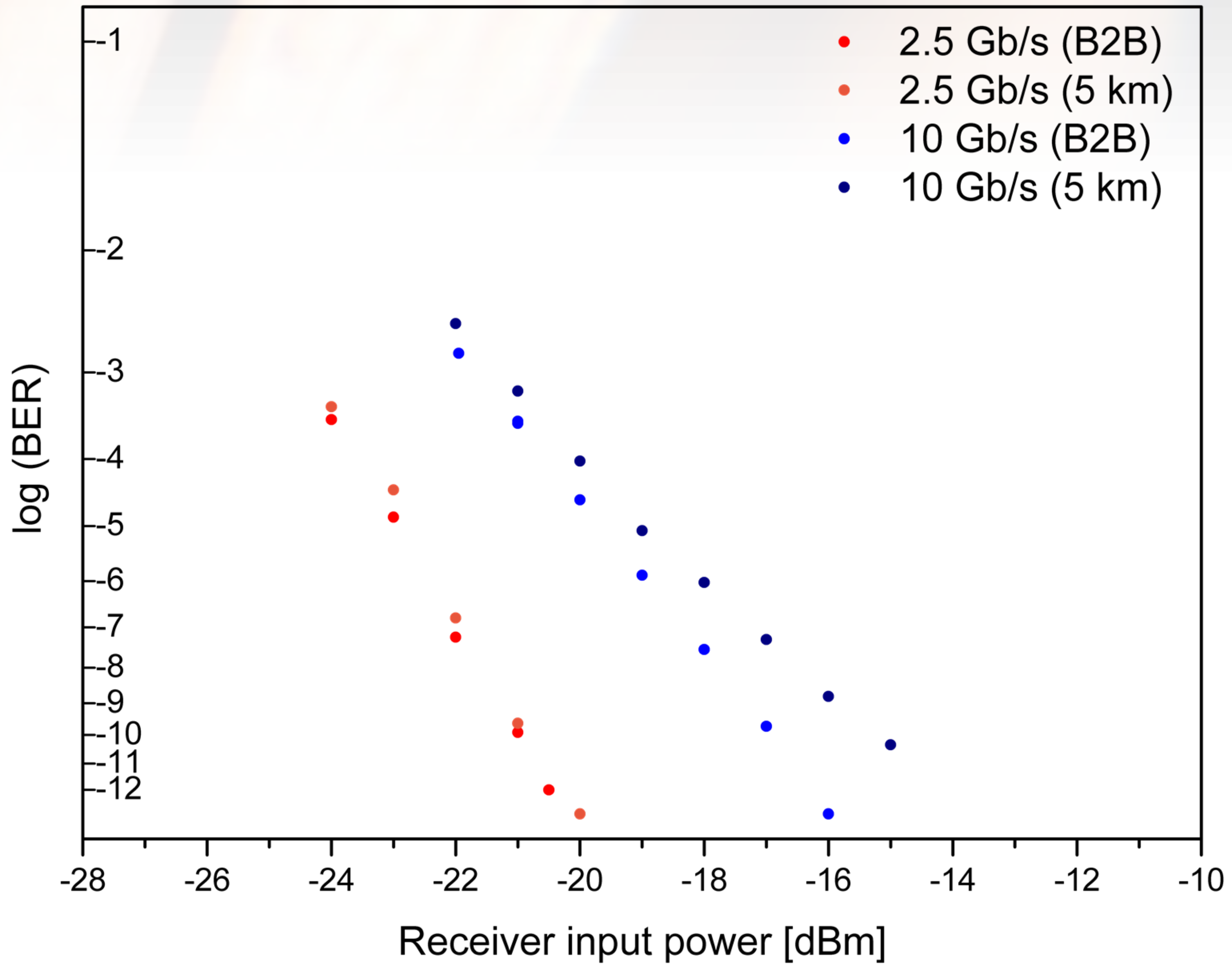


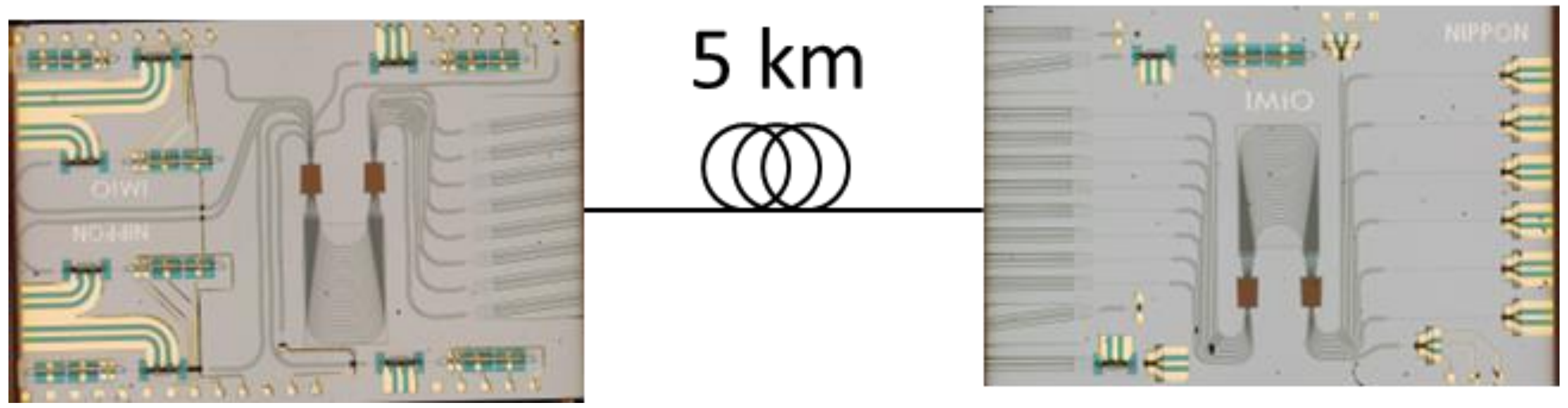
- 6 channels, L-band
- $\Delta\lambda$ = 0.8 nm (100 GHz grid)
- output power 0.2 mW
- single mode operation, SMSR > 40 dB

Multi-wavelength transmitters for telecom and datacom

Four generations of ASPICs designed, developed and tested (TRL6)

	2.5 Gb/s	5 Gb/s	10 Gb/s
B2B	 ER = 10 dB QF = 9	 ER = 9 dB QF = 8	 ER = 8 dB QF = 6
5 km	 ER = 7 dB QF = 6	 ER = 7 dB QF = 6	 ER = 6 dB QF = 5





- open eye-diagrams for modulation speed up to 10 Gb/s and distance up to 5 km
- error-free operation confirmed

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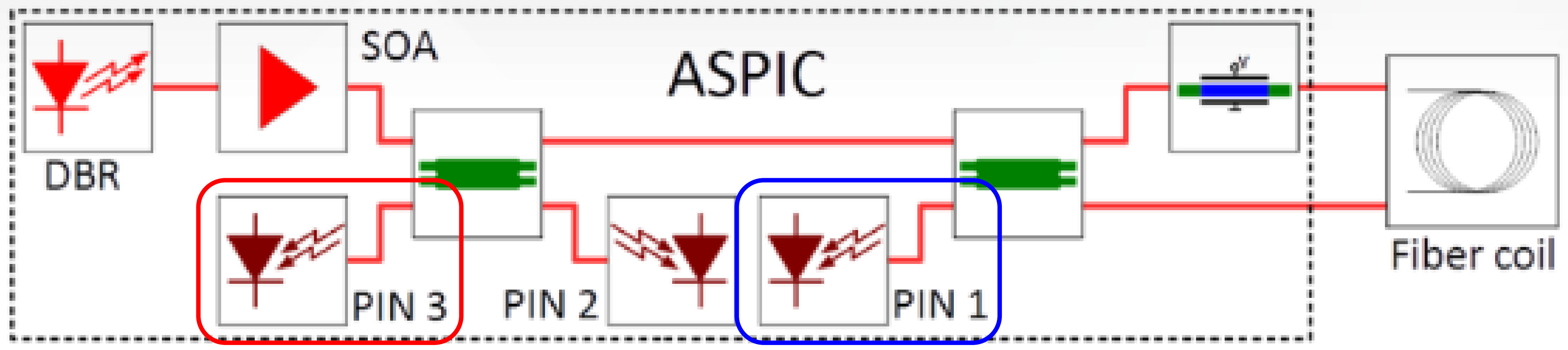
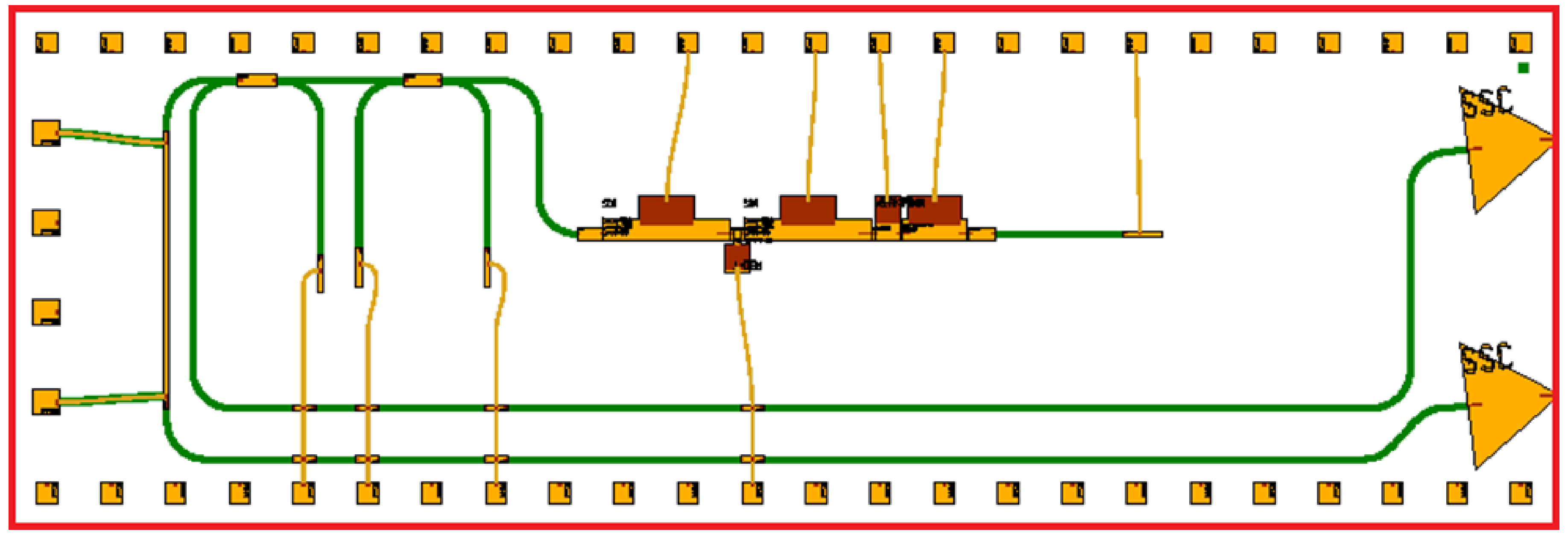
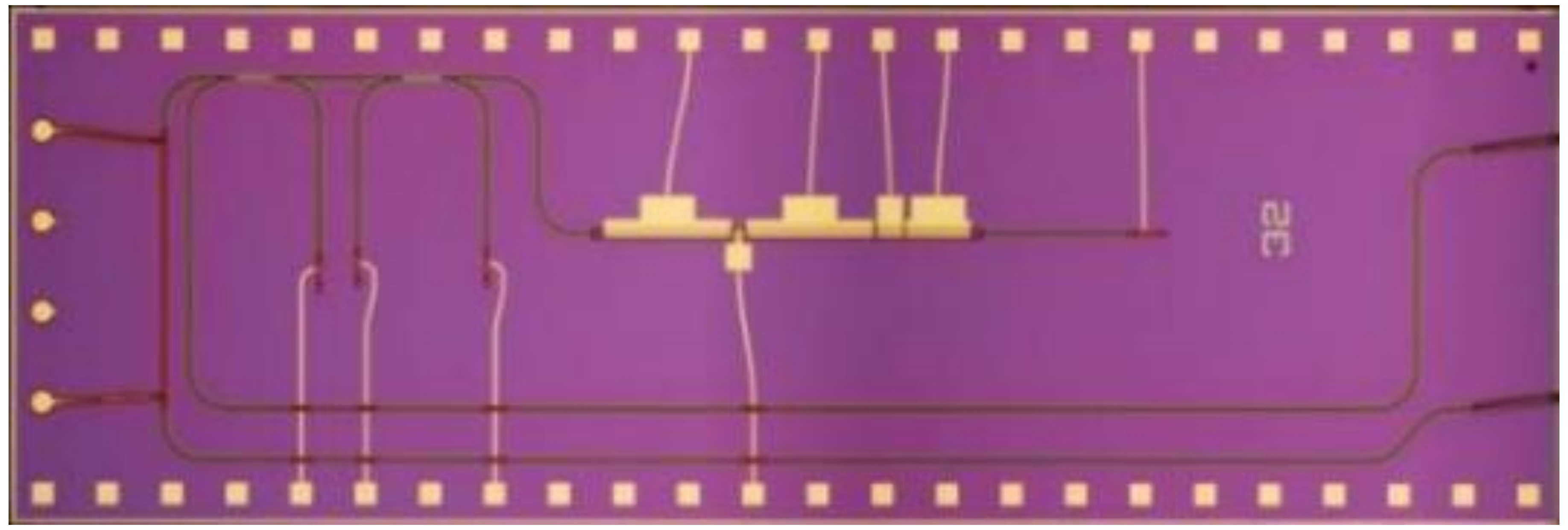
Integrated optical gyroscopes

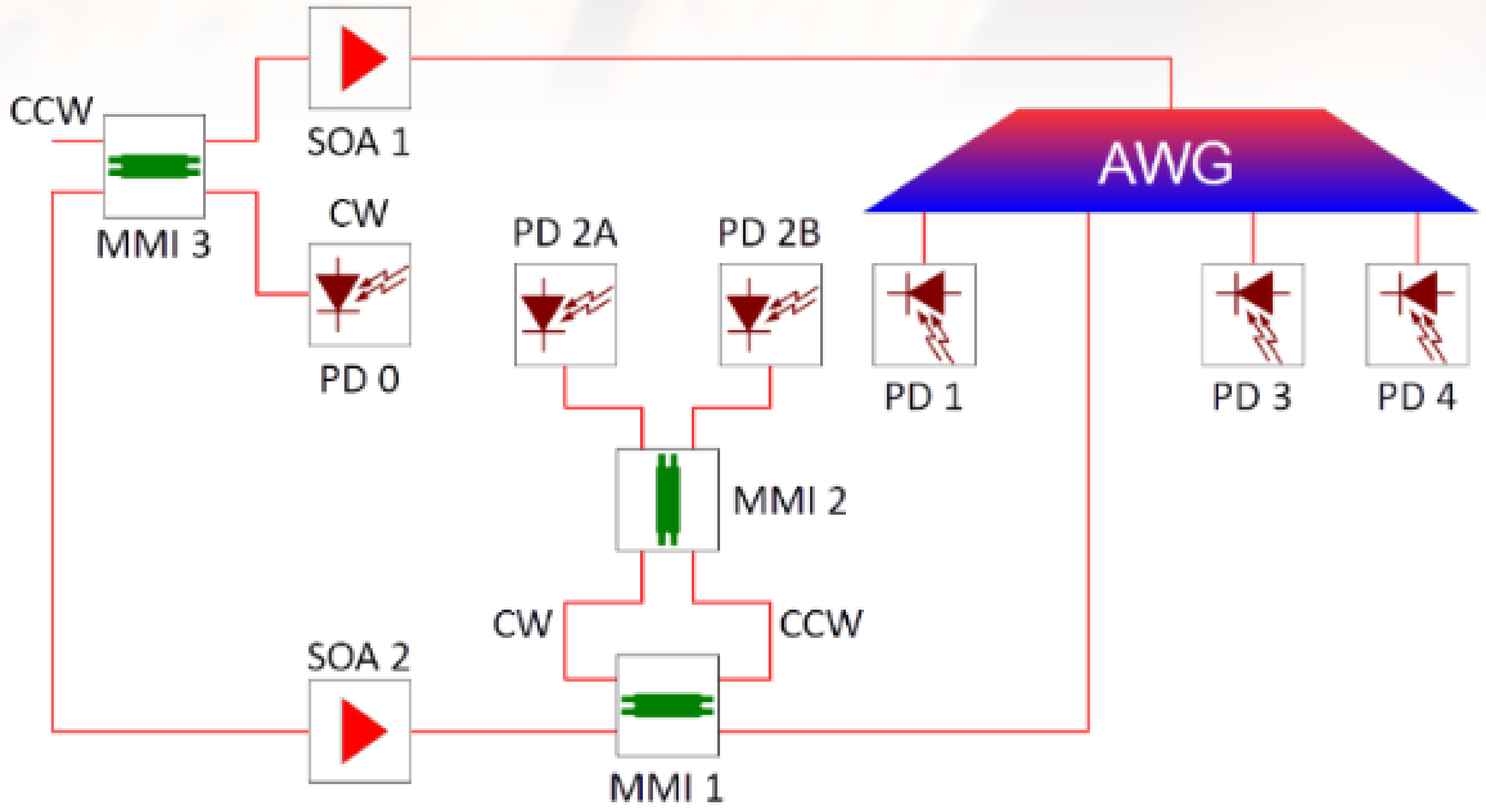
ASPIC-based interrogator for interferometric fiber-optic gyroscope (iFOG)

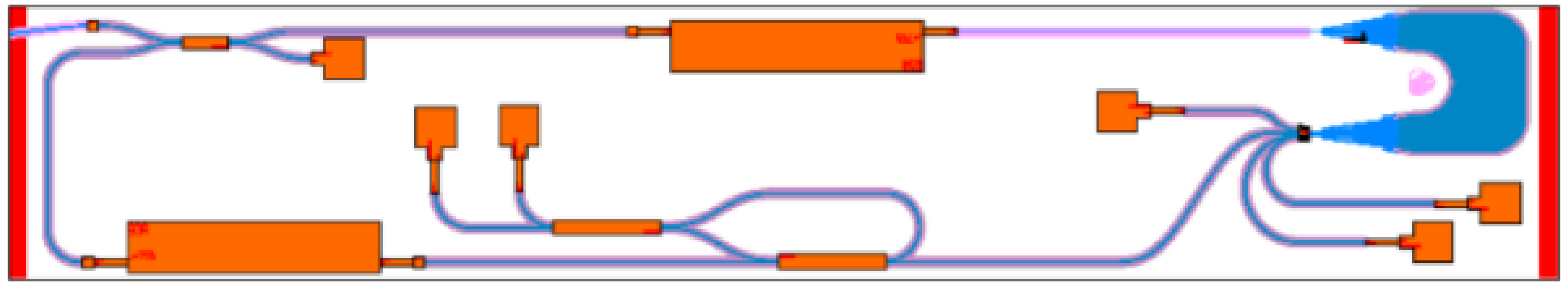


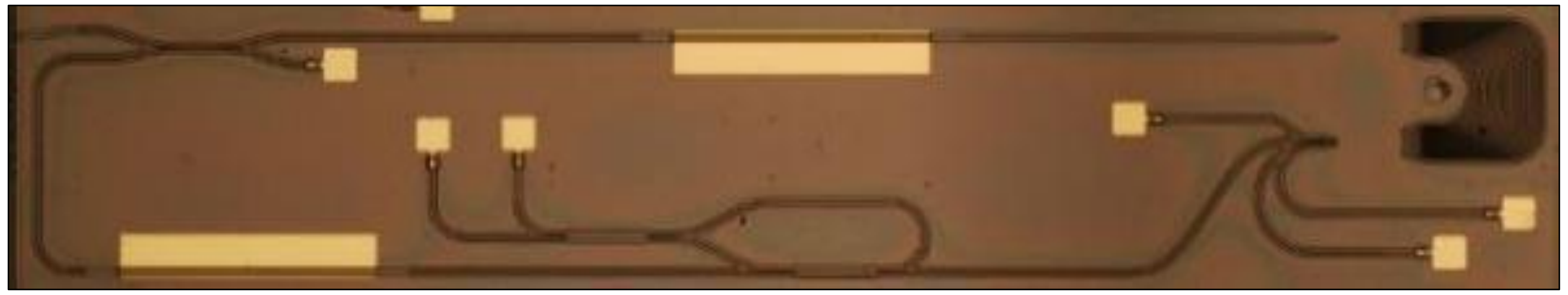




ASPIC-based single-mode ring laser for ring laser gyroscope (RLG)







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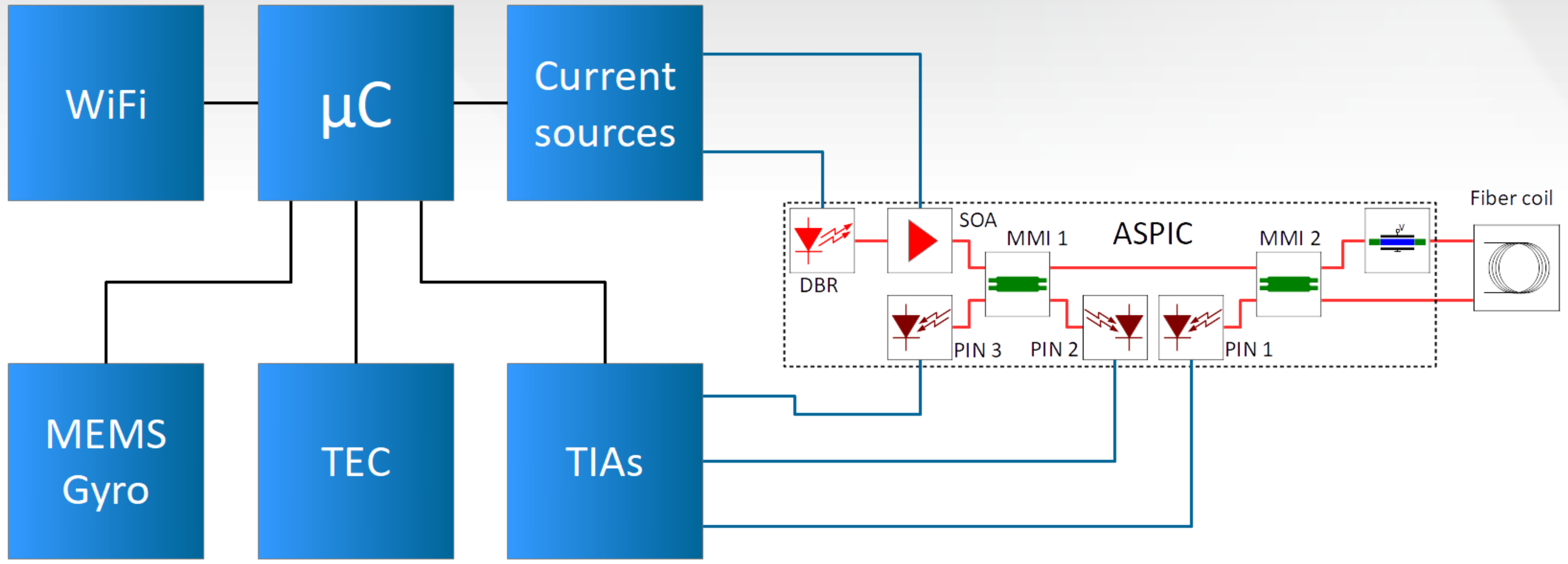
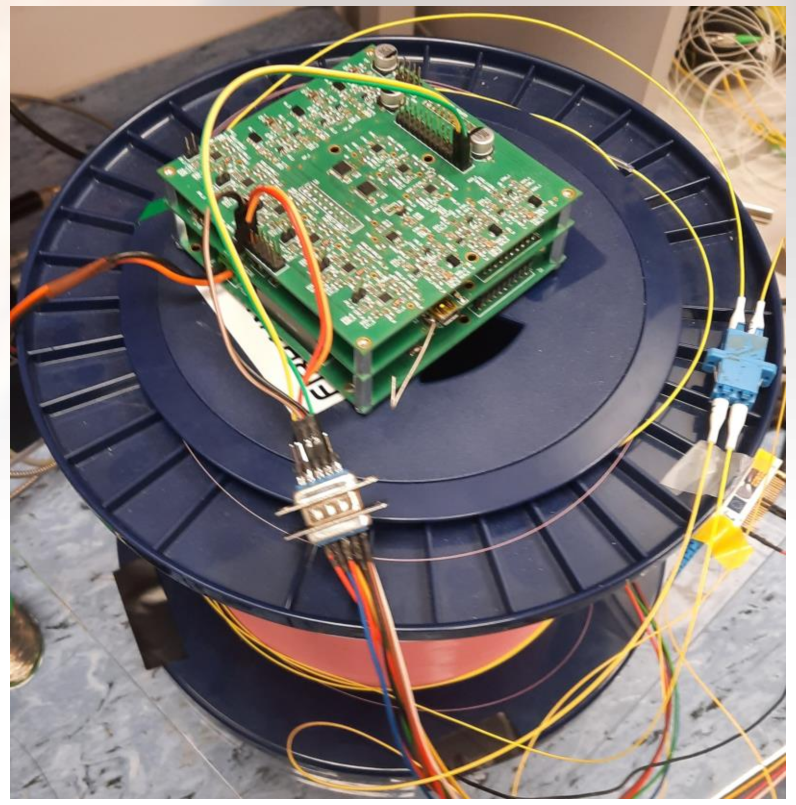
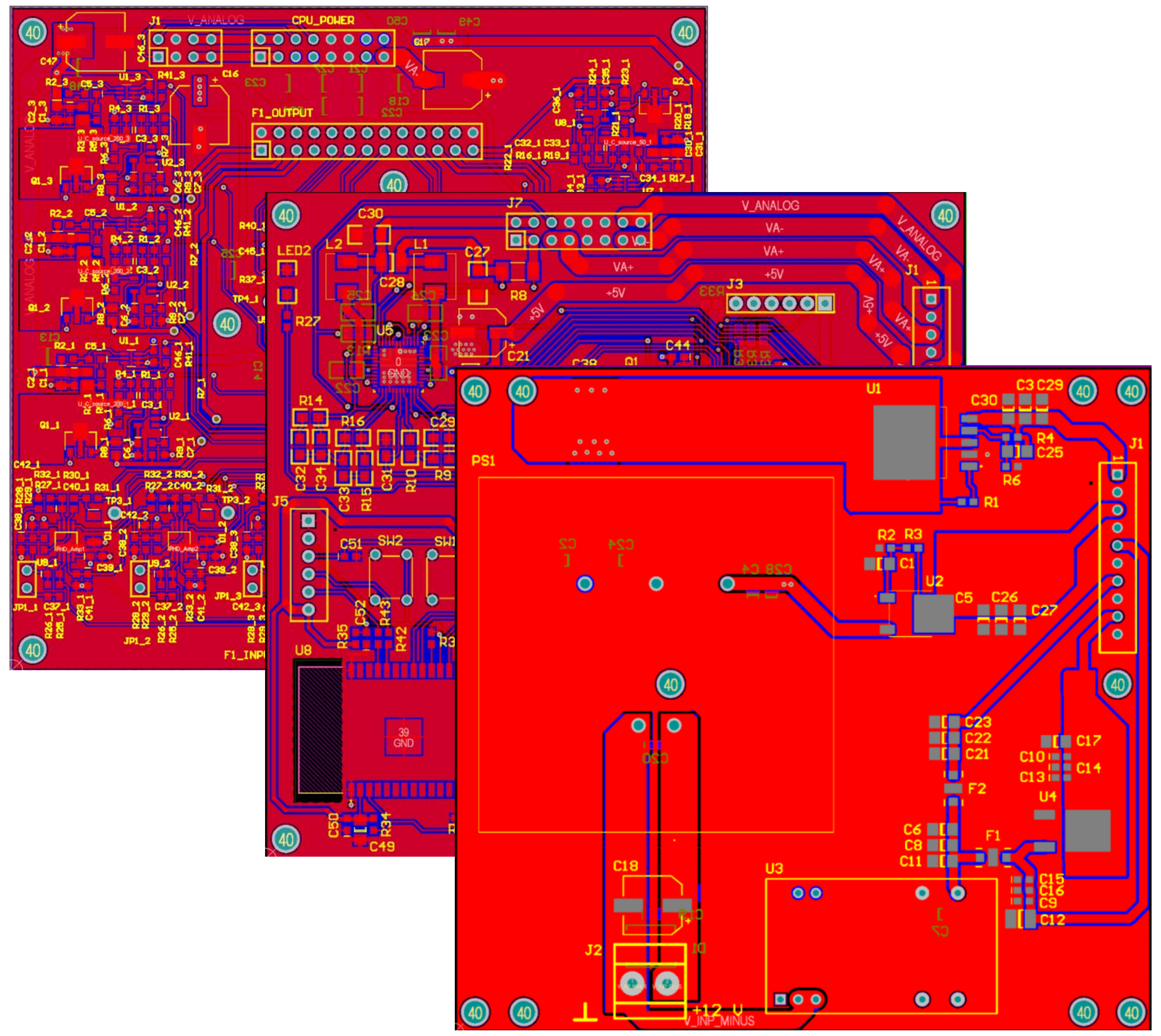
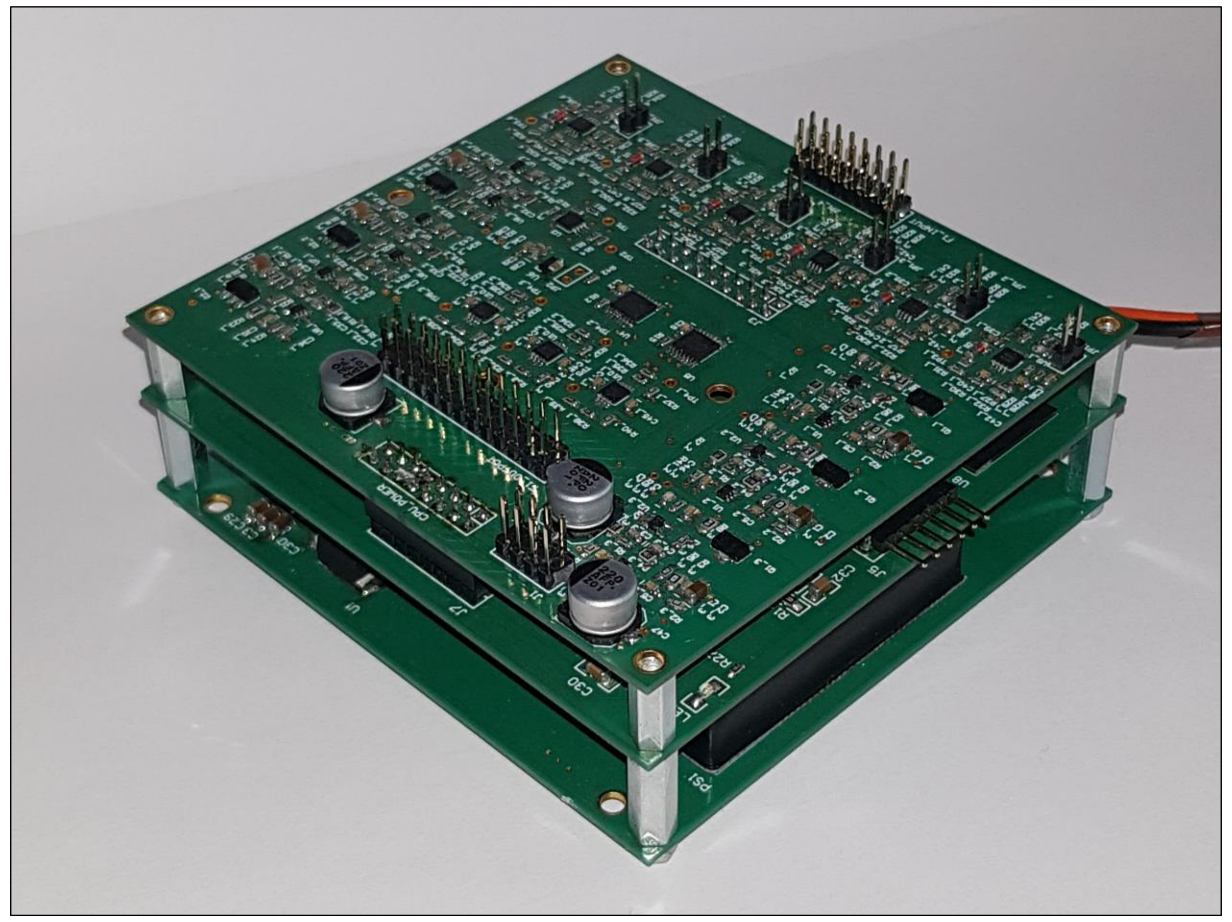
IFOG system demonstrator – gyroscope experiments



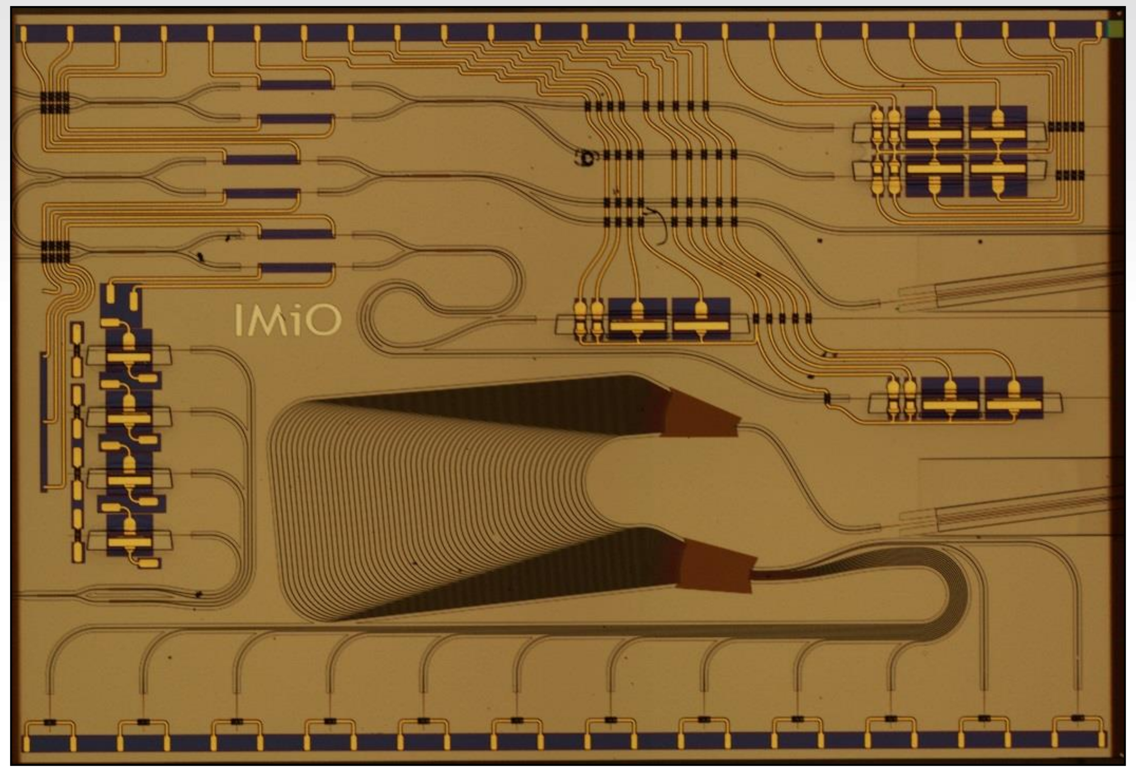




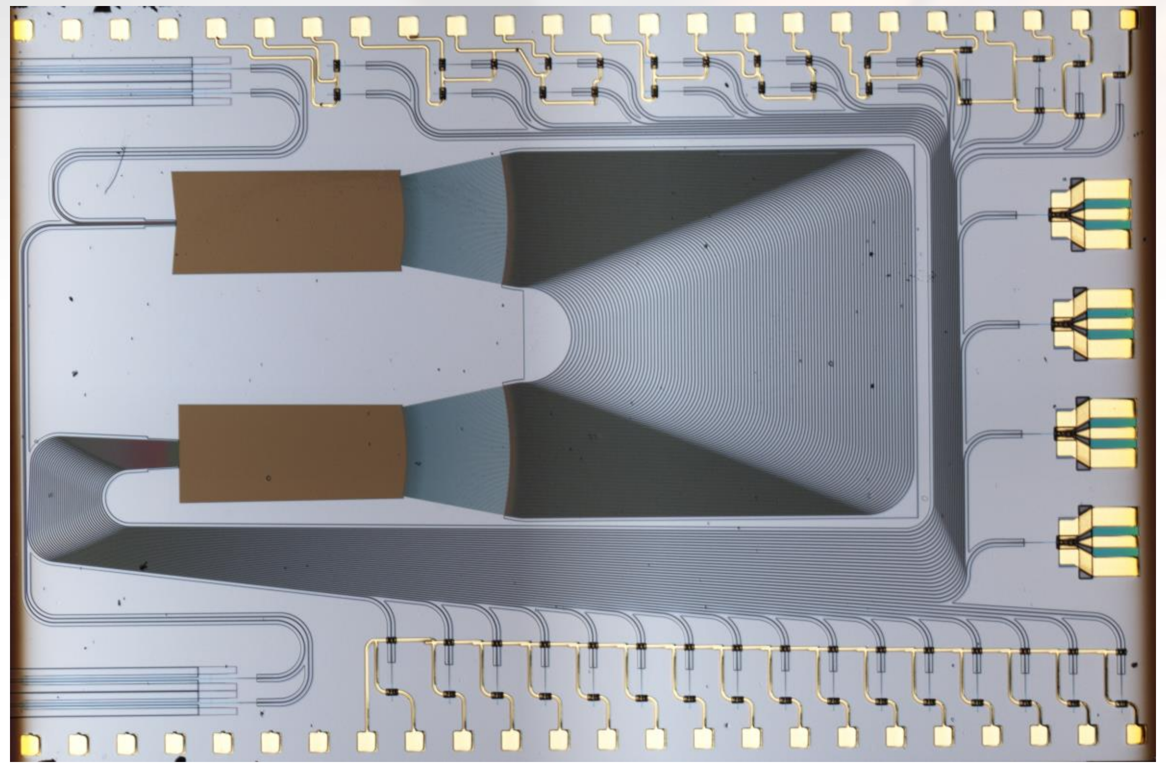


Integrated interrogators of fiber Bragg gratings

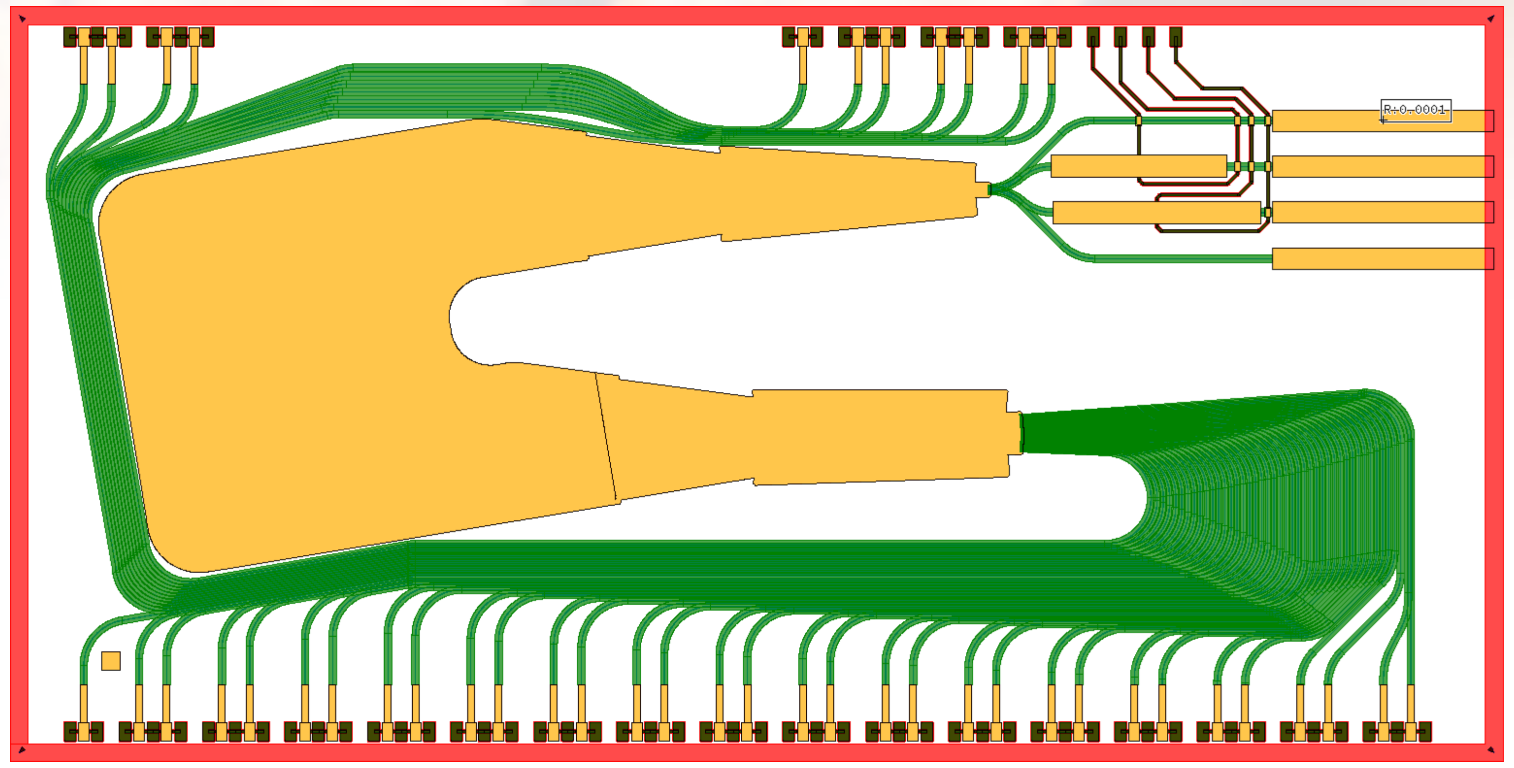
Line of AWG–based interrogators (TRL6/TRL7)



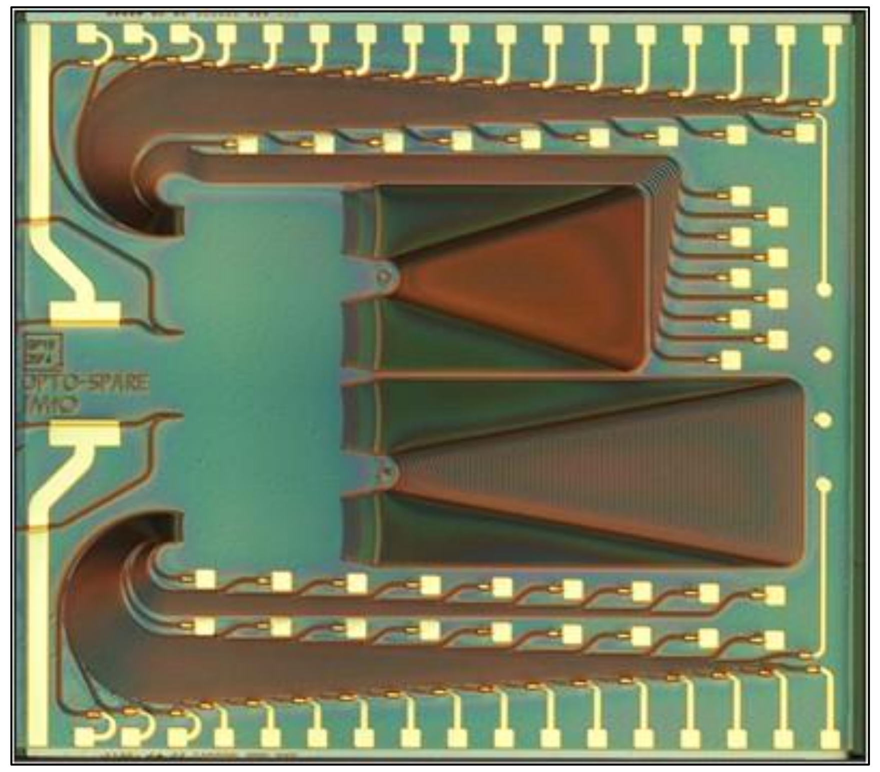
- 12 channels
- Δf = 100 GHz
- foundry: Heinrich-Hertz Institute



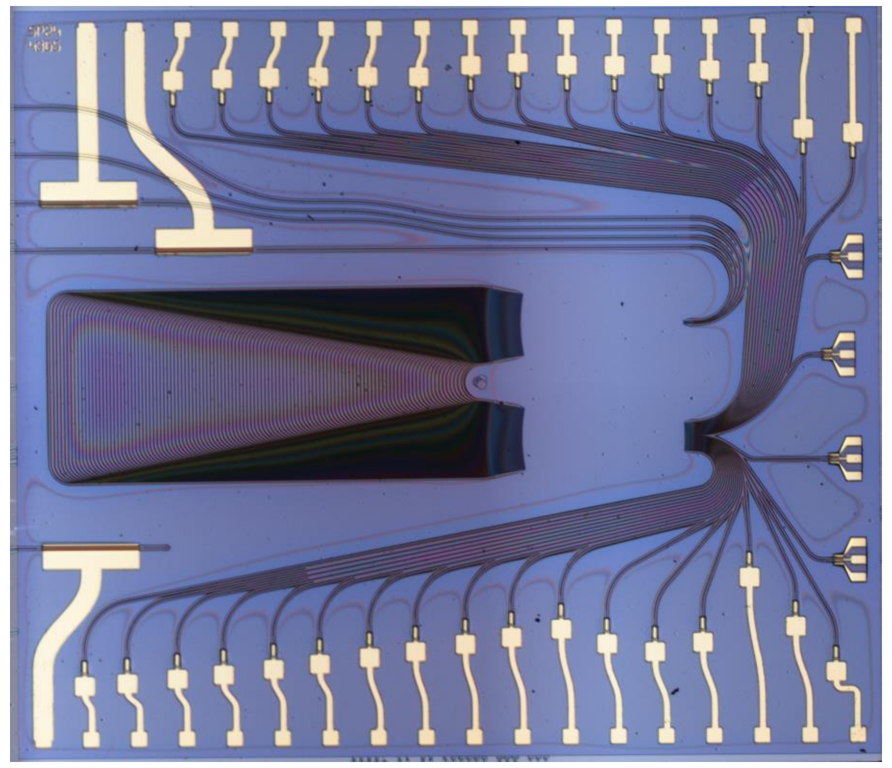
- 36 channels
- Δf = 50 GHz
- foundry: Heinrich-Hertz Institute



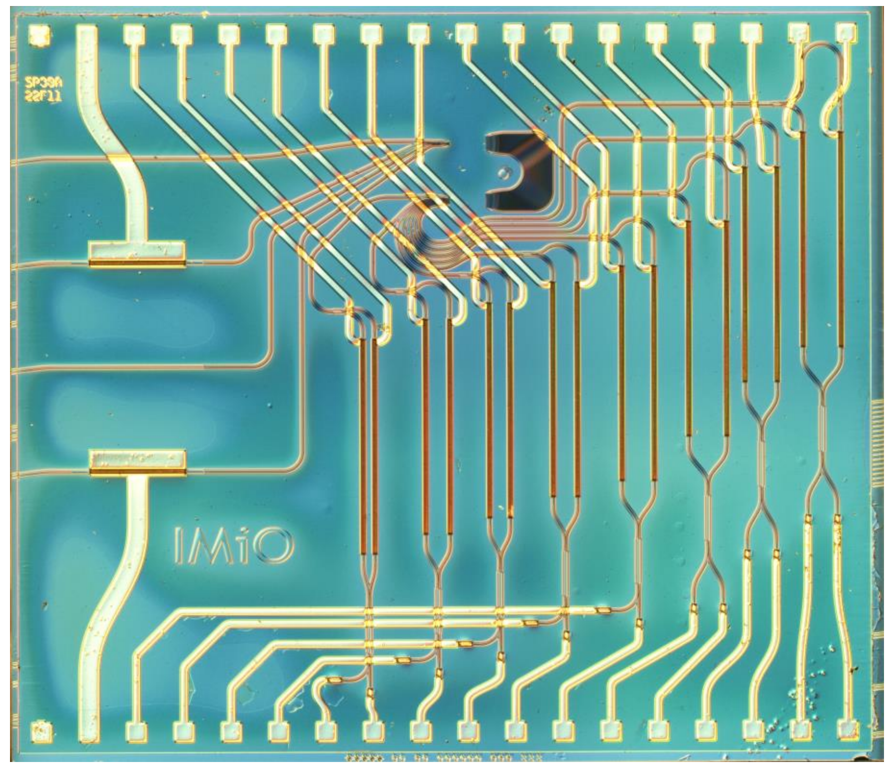
- 44 channels
- Δf = 50 GHz
- foundry: Heinrich-Hertz Institute



- 36 channels
- Δf = 50 GHz
- foundry: SMART Photonics



- 36 channels
- Δf = 50 GHz
- foundry: SMART Photonics

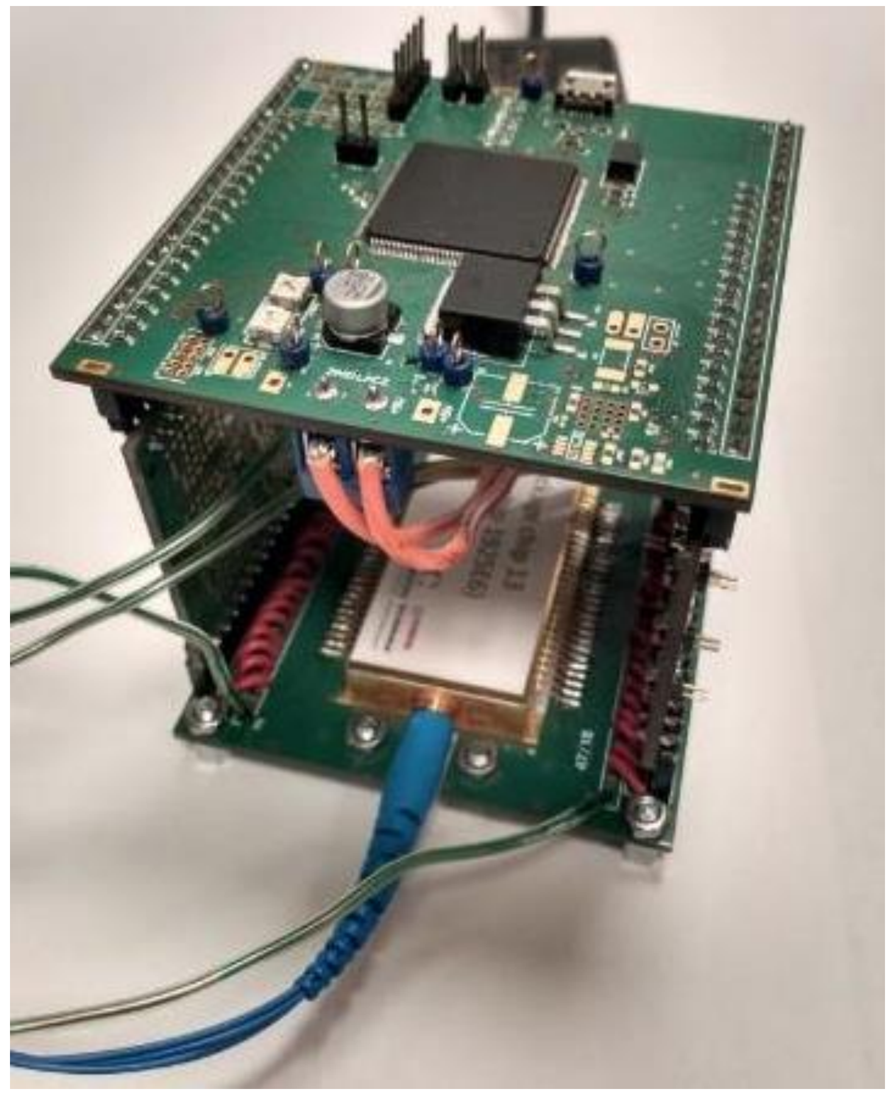
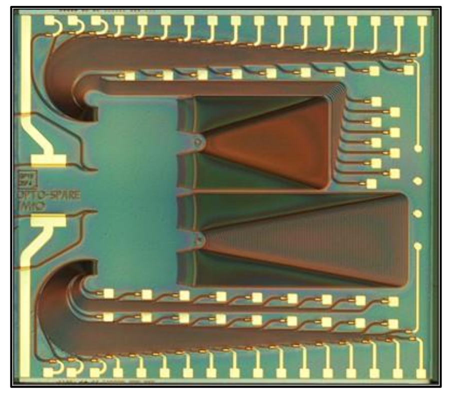


- AMZI-based interrogator
- foundry: SMART Photonics

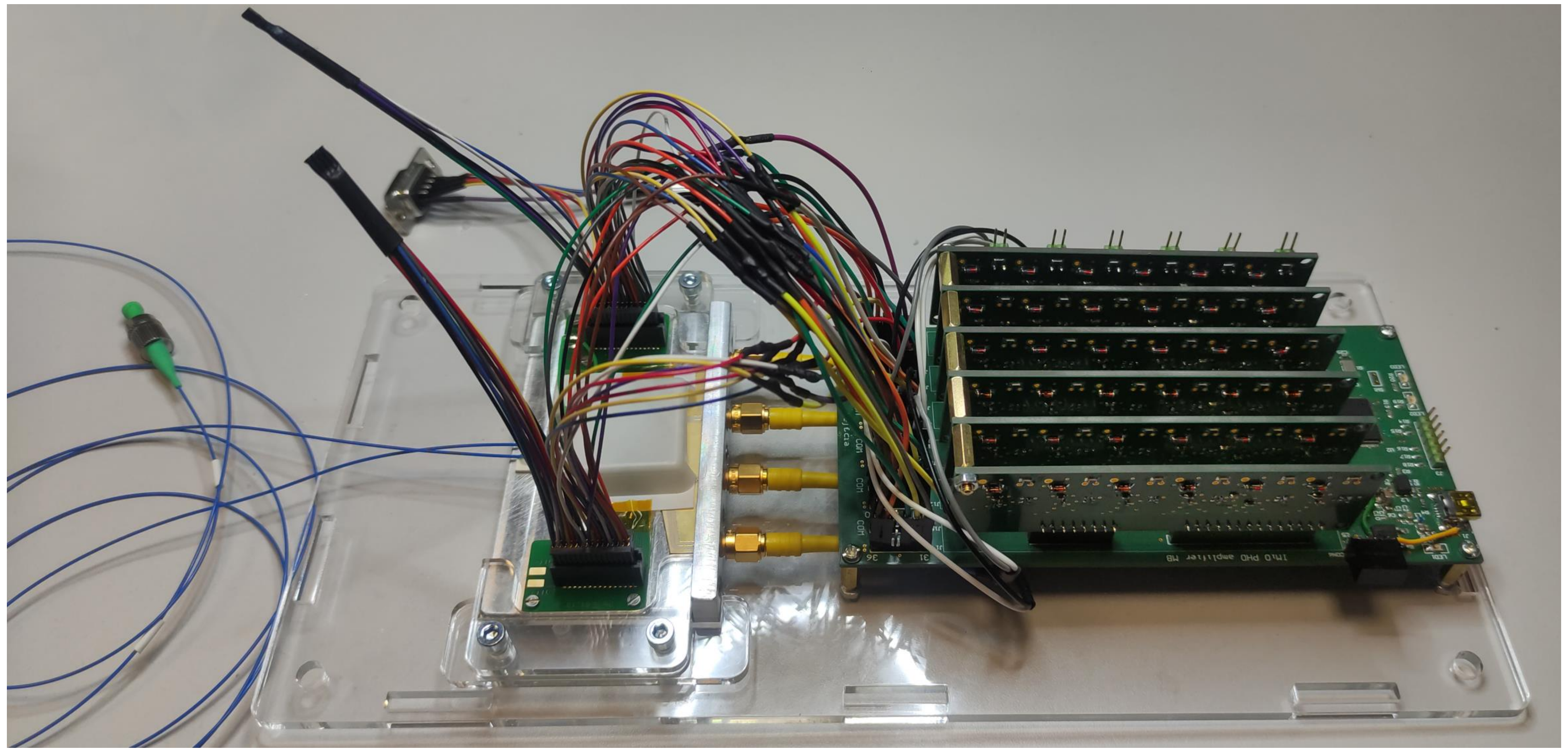
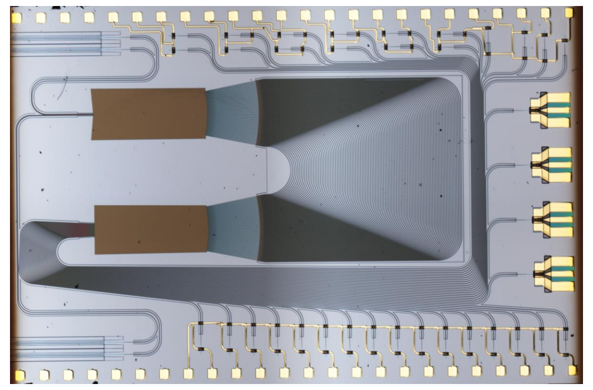
Line of AWG–based interrogators (TRL6/TRL7)

Demonstrators equipped with custom-made driving electronic systems

- micro-controller
- analog frontend: an array of transimpedance amplifier
- adjustable sampling rate 10 Hz – 10 kHz
- temperature control
- USB interface

ASPIC installed
- 18 channels
- Δf = 50 GHz
- foundry: SMART Photonics

ASPIC installed
- 36 channels
- Δf = 50 GHz
- foundry: Heinrich Hertz Institute

Integrated interrogators of fiber Bragg gratings

VIGO PHOTONICS

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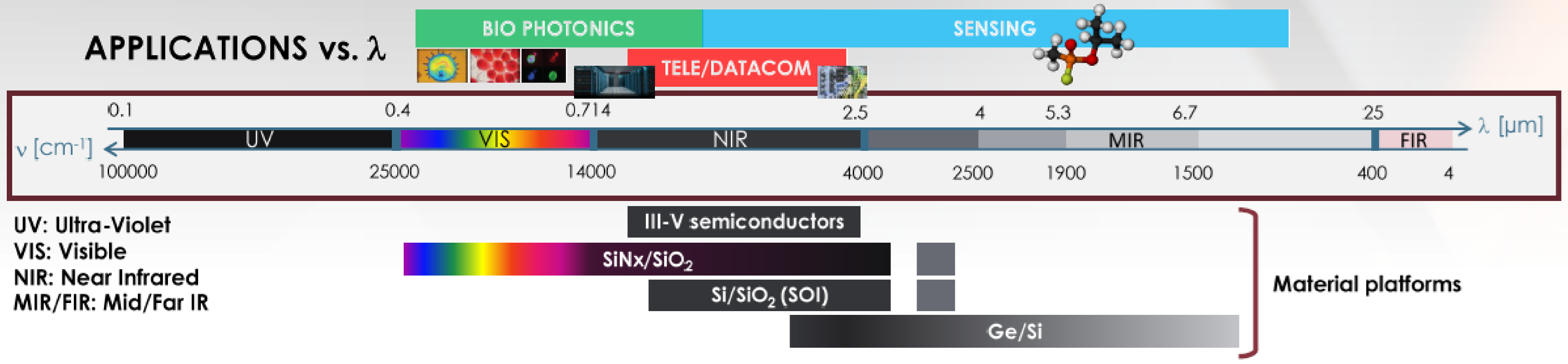
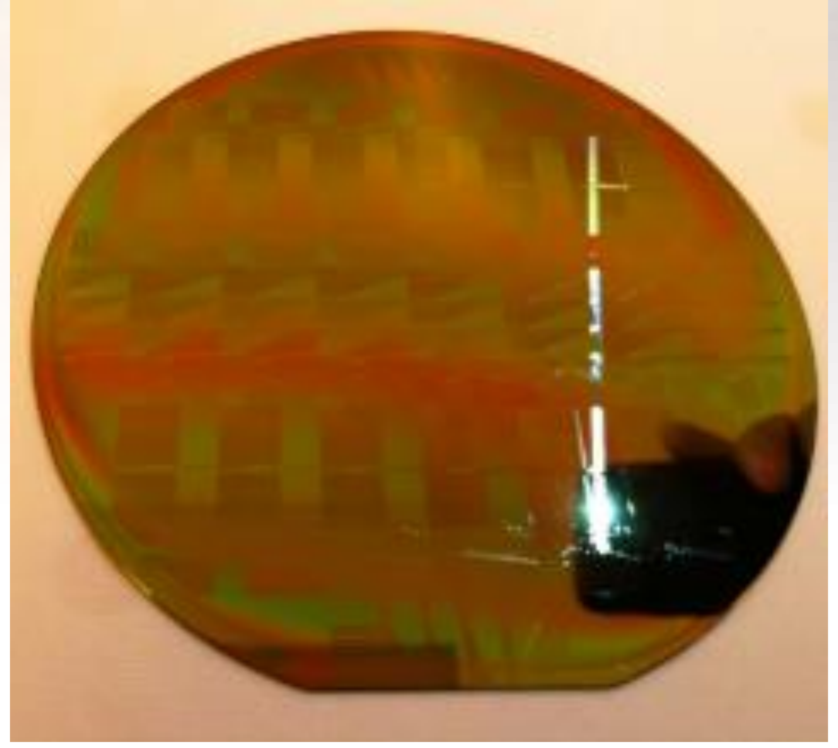
PICs technology in Poland – silicon nitride

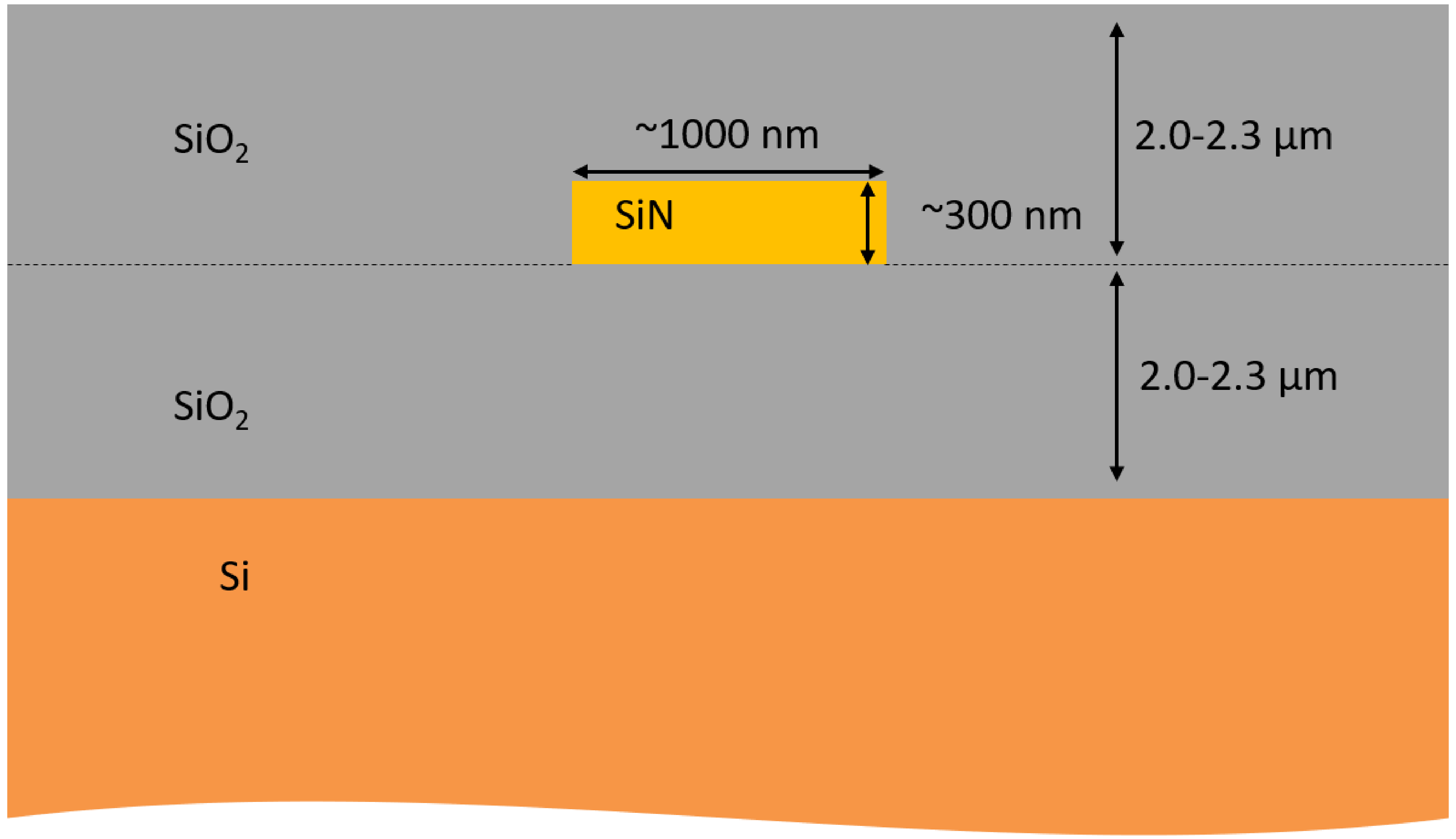
Silicon nitride technology at WUT CEZAMAT



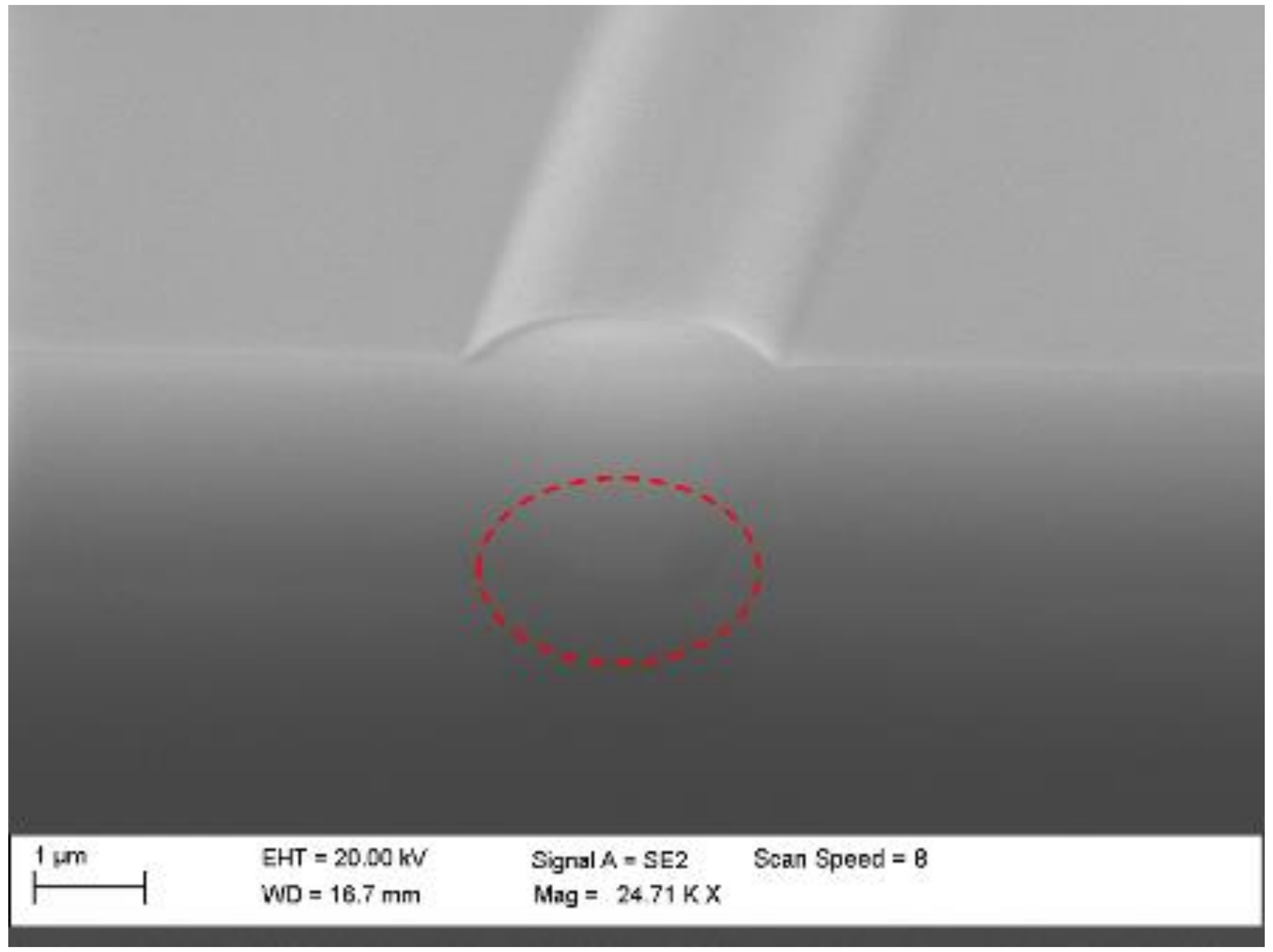
P. Munoz et al., „Silicon Nitride Photonic Integration Platforms for Visible, Near-Infrared and Mid-Infrared Applications", Sensors. 2017;17:2088. doi: 10.3390/s17092088



Waveguide cross-section



SEM image of fabricated waveguides



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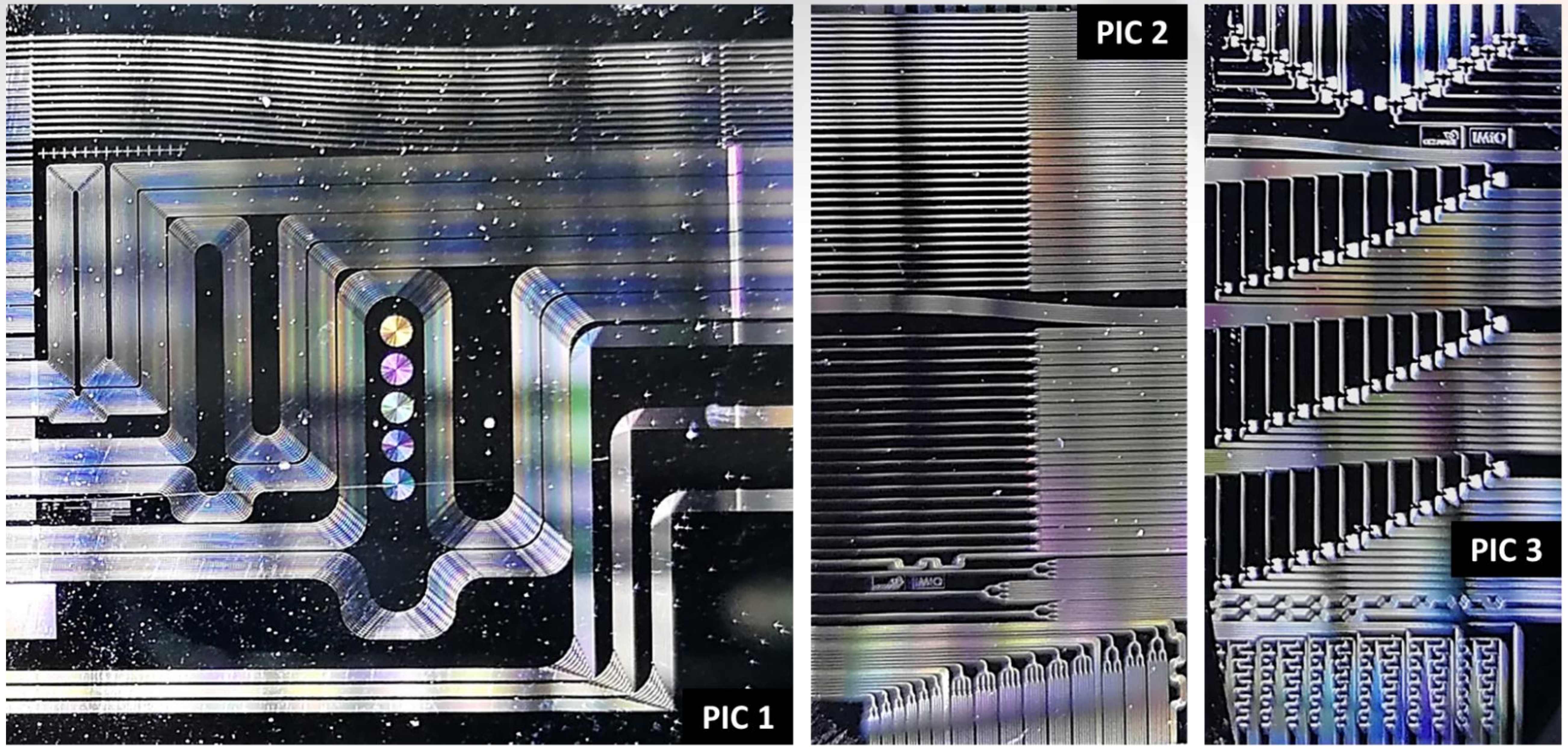
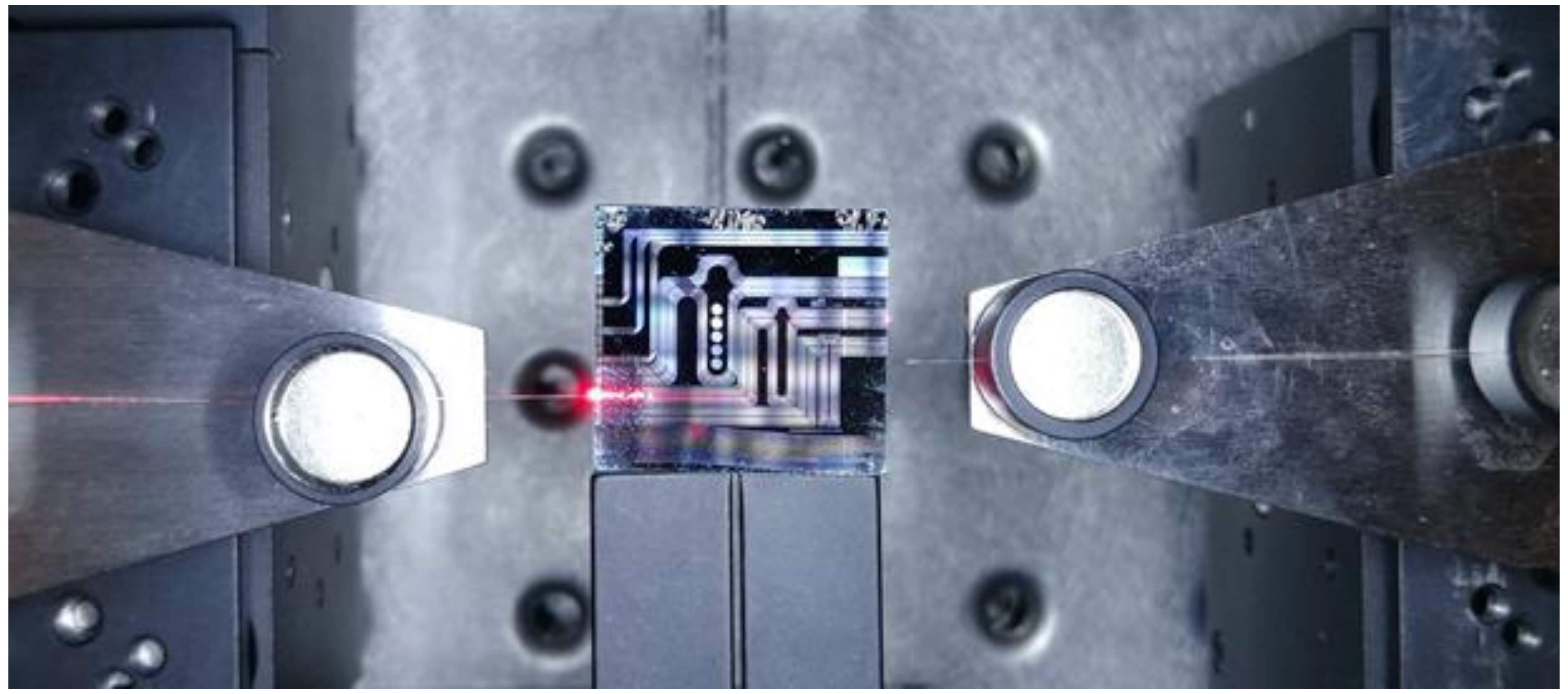
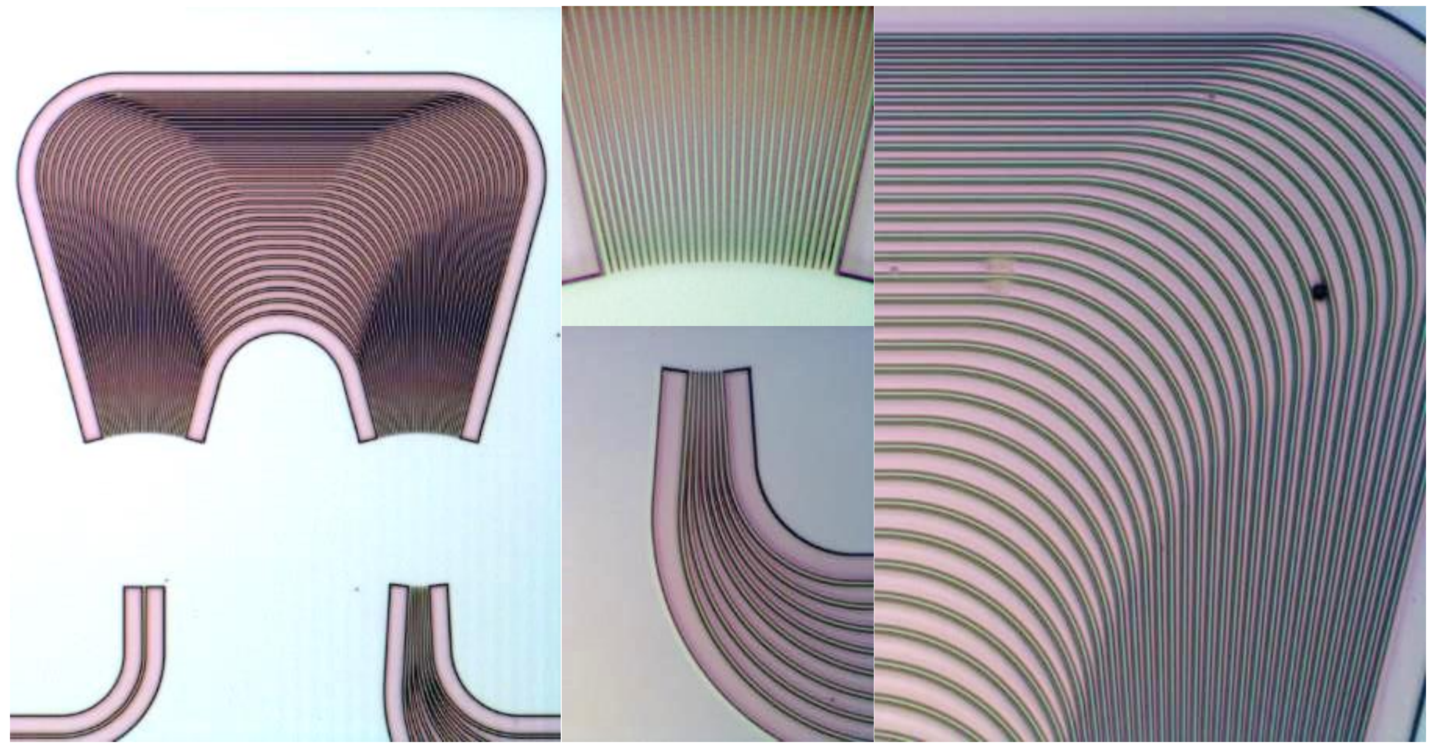
Silicon nitride technology at WUT CEZAMAT

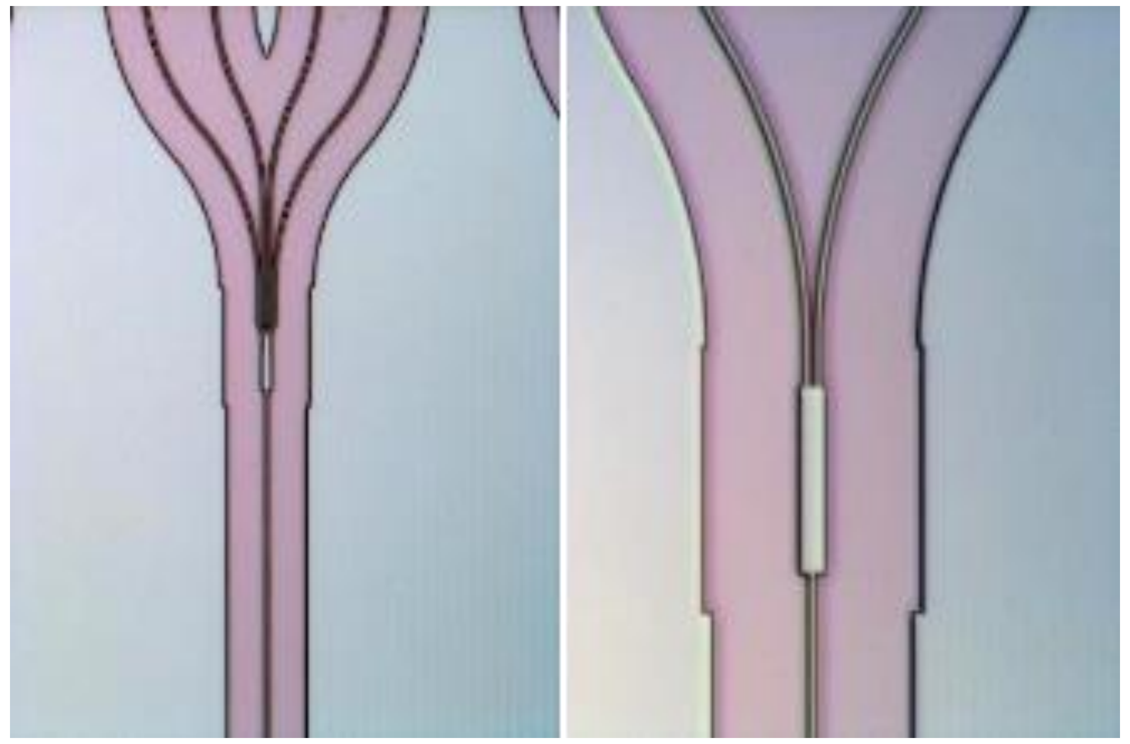


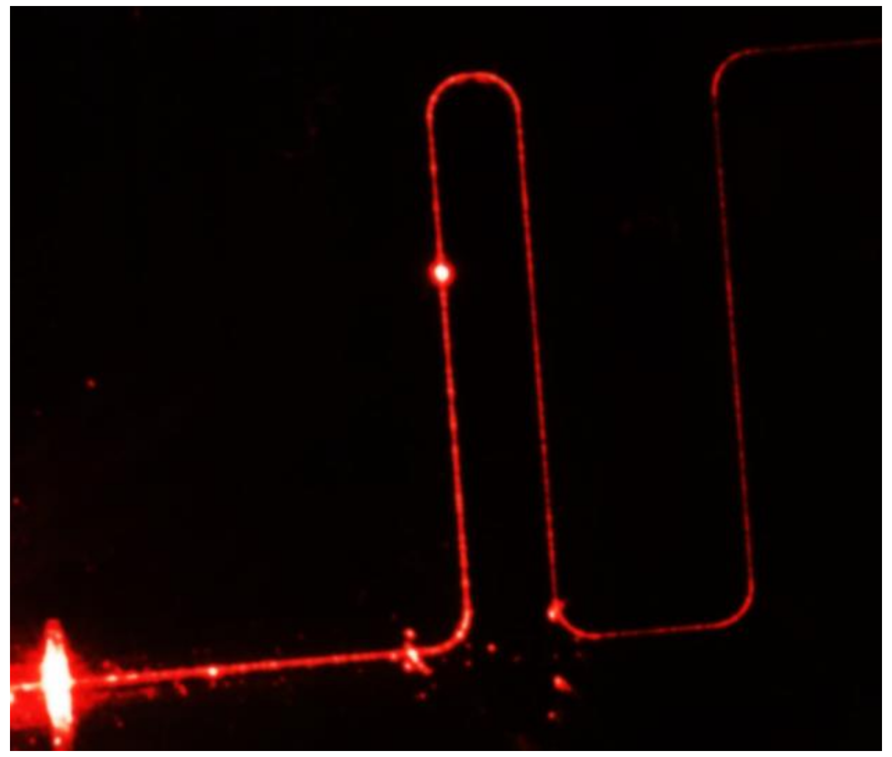
Passive waveguides:

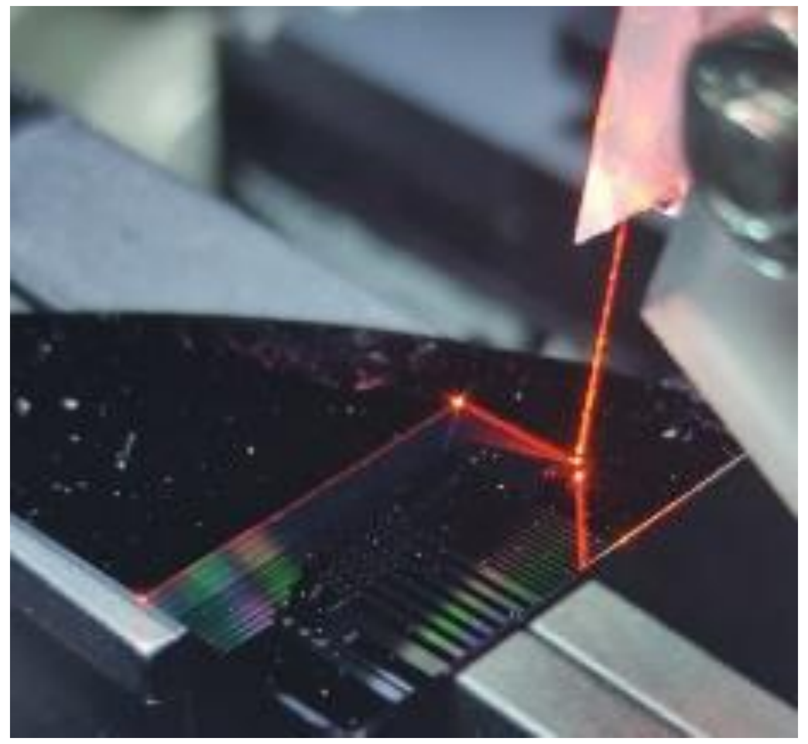
- attenuation between 1.7 and 3.7 dB/cm
- average loss (90° bend, 100 μm radius) 0.2 dB











VIGO PHOTONICS

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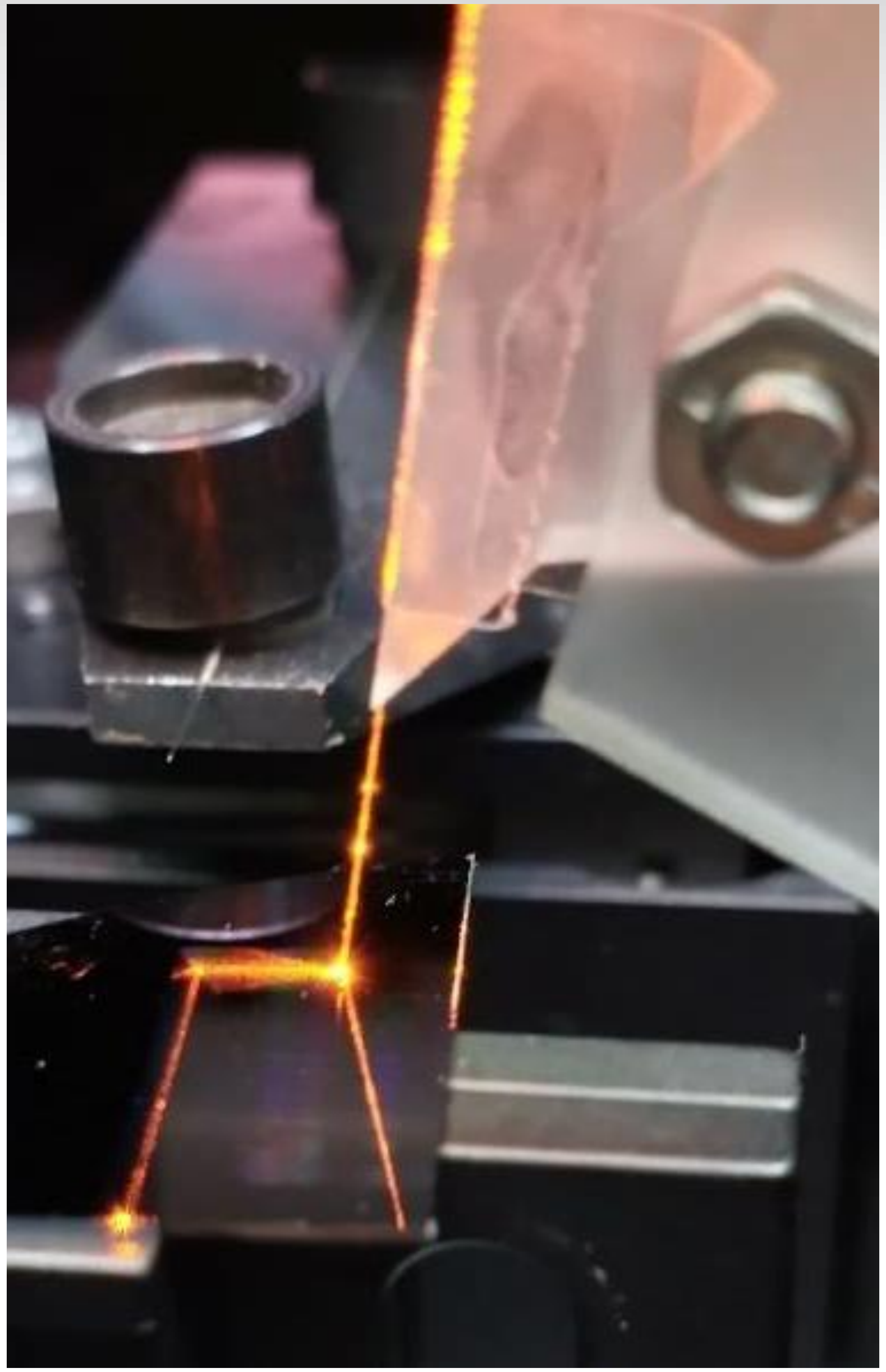
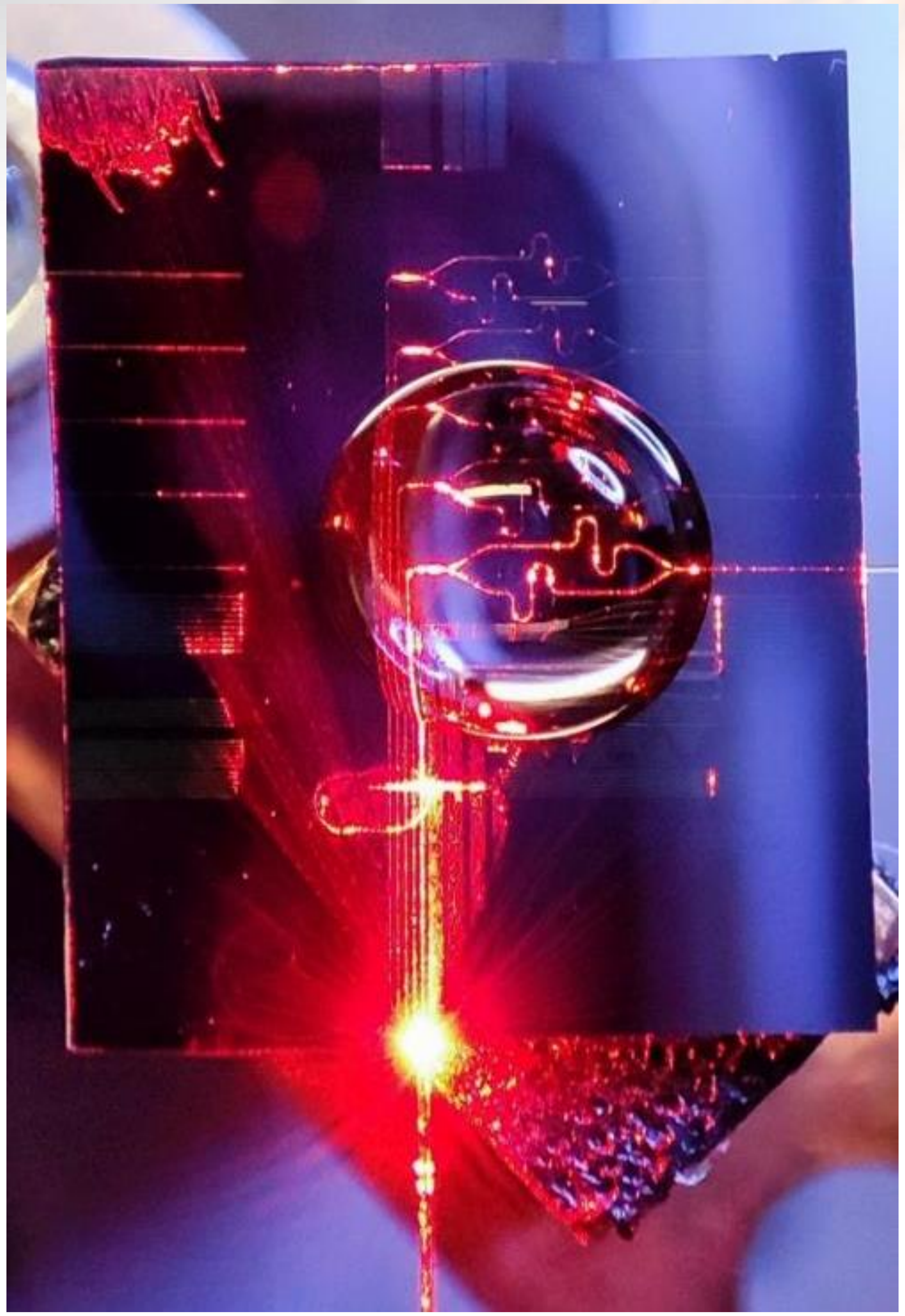
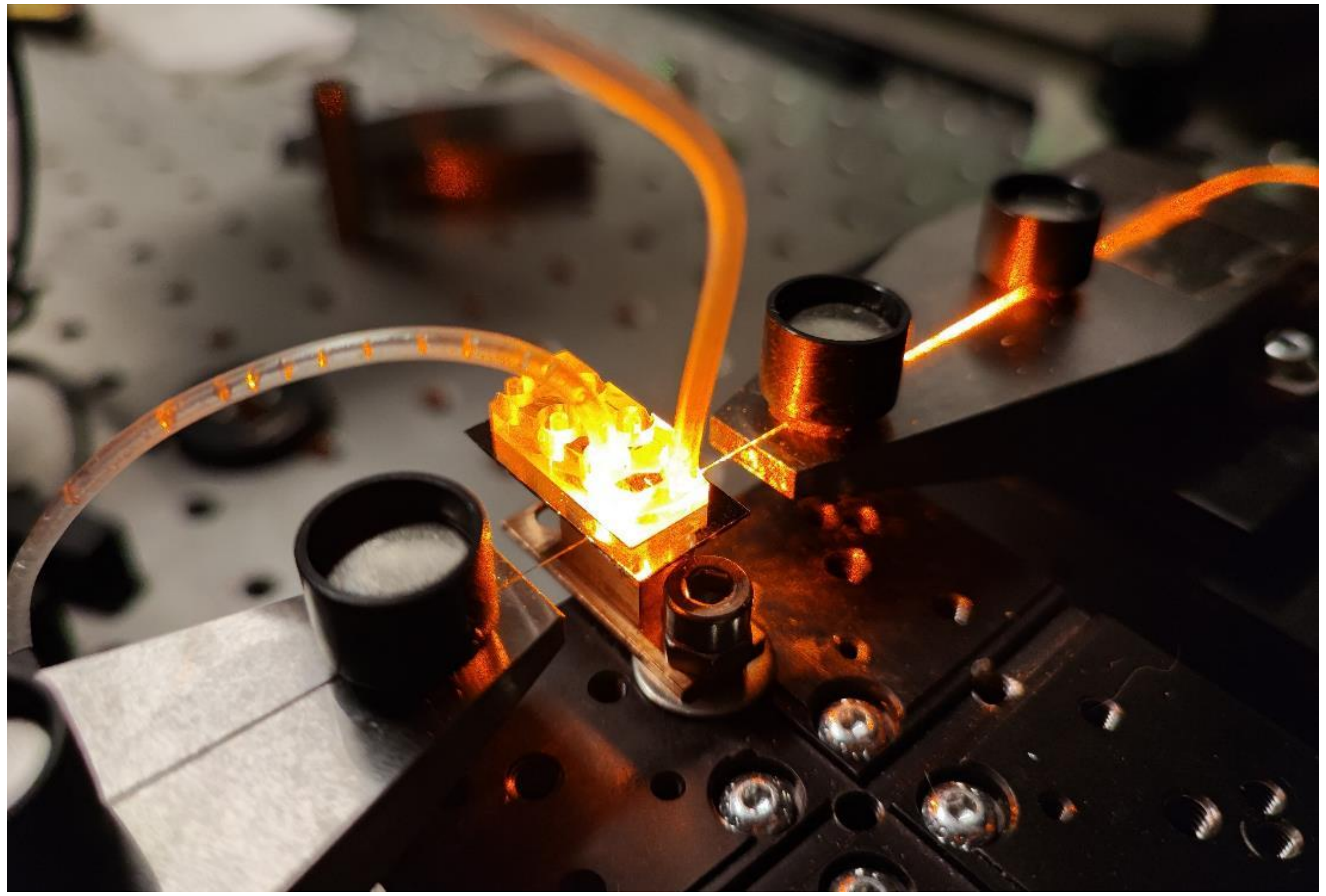
Silicon nitride technology at WUT CEZAMAT





SiN waveguides

- optical interface – butt coupling and grating coupling
- integrated structures with microfluidics interface for sensing applications



VIGO PHOTONICS

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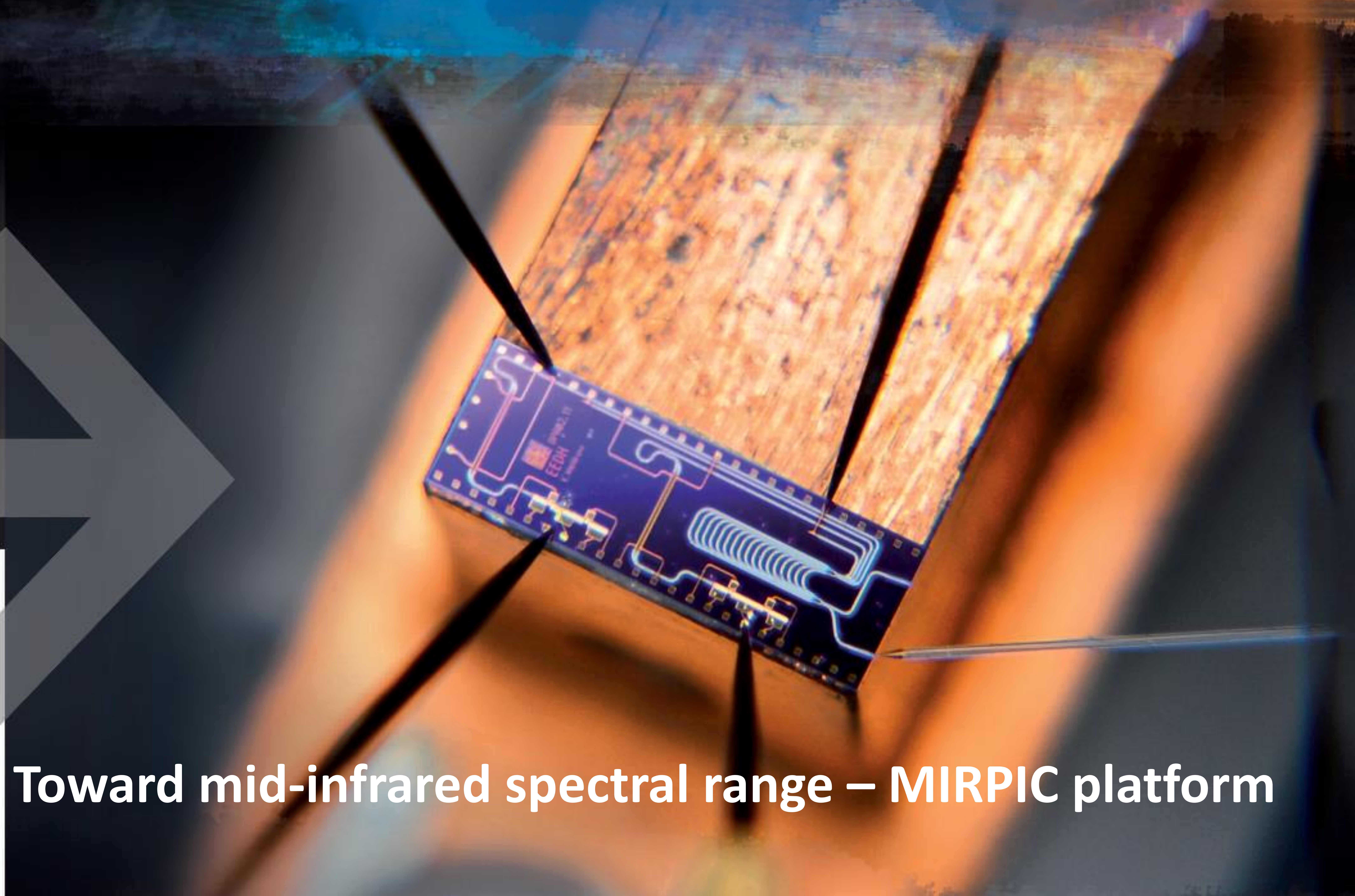
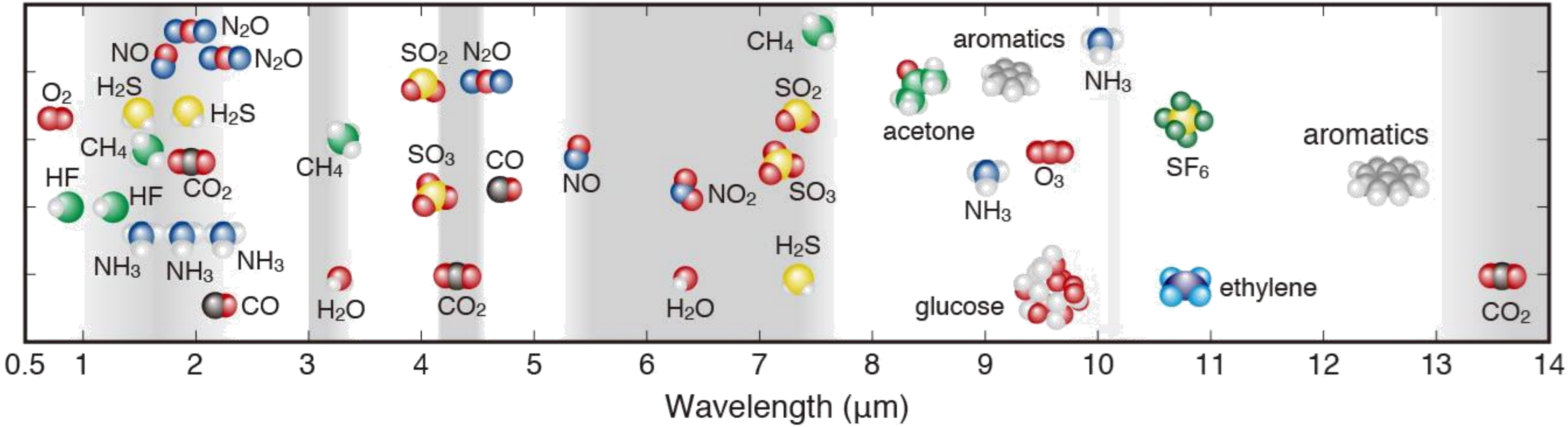


POLITECHNIKA WARSZAWSKA
WARSAW UNIVERSITY OF TECHNOLOGY

VIGO PHOTONICS

Toward mid-infrared spectral range – MIRPIC platform

Nearly all chemical vapors have a unique "molecular fingerprints" in mid-infrared



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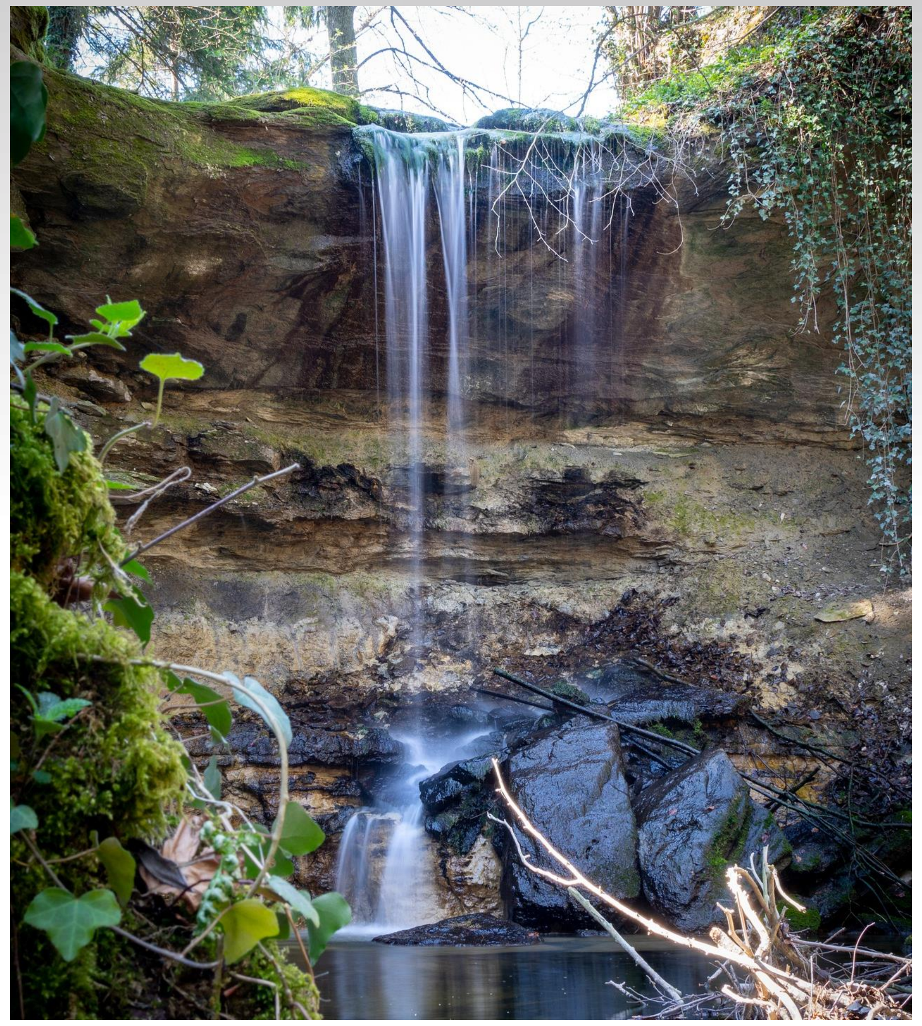
MIR photonics

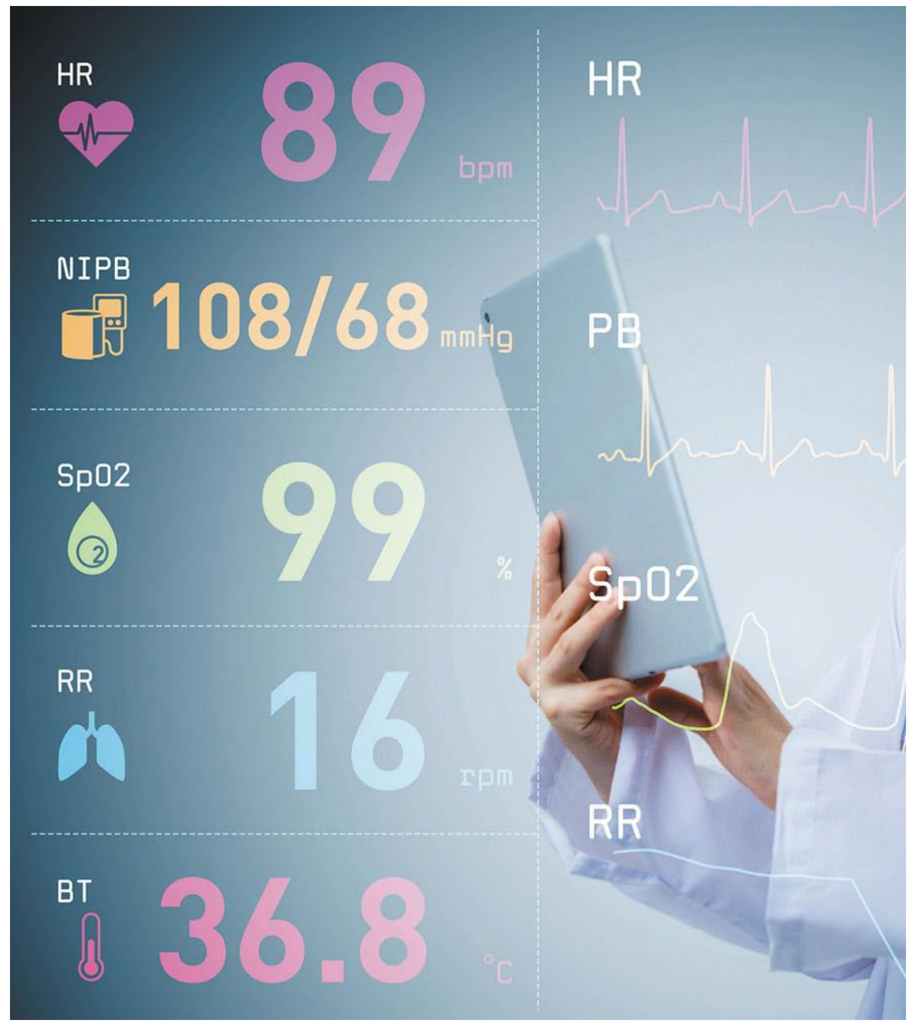

Environment protection


Greenhouse gases emission monitoring


Modern agriculture


Automotive

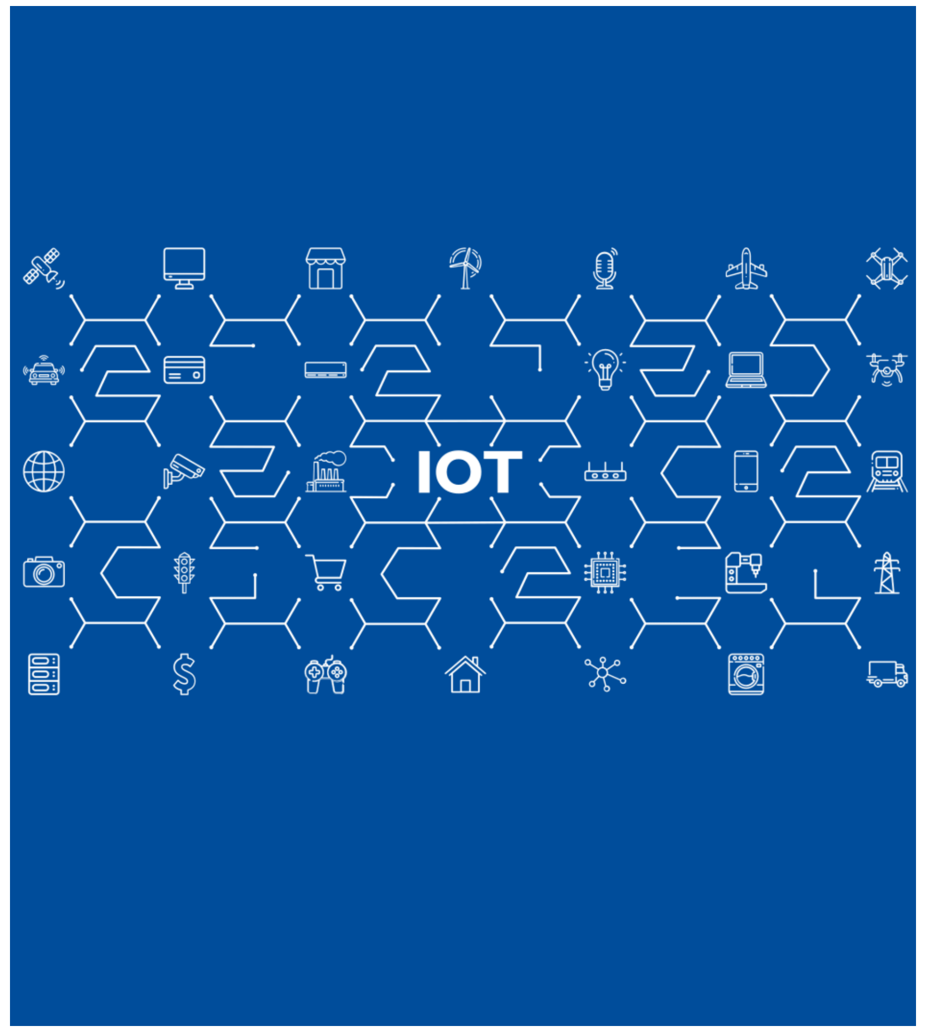

Special applications



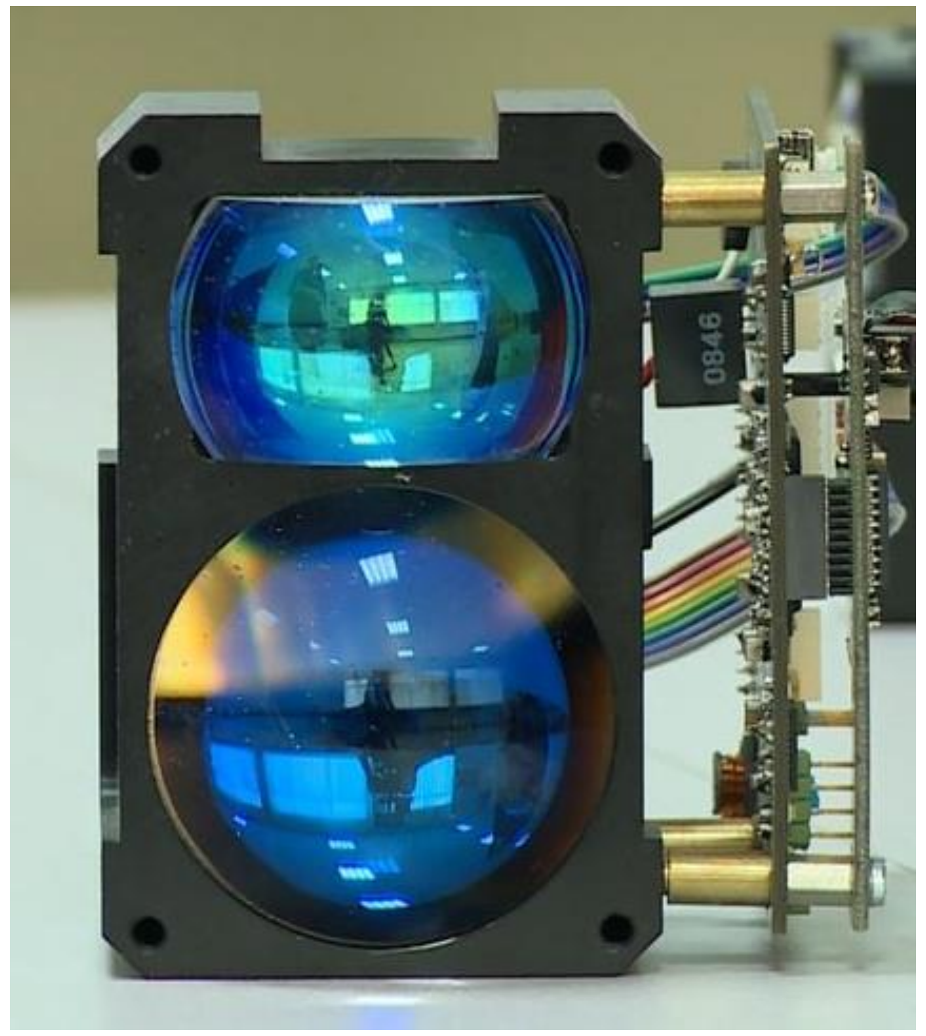
Medicine


Security and safety

Defense



Internet of Things


FSO Communication

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Environment

"Photonic sensing technologies are a critical element in (...) environmental hazard monitoring"

- air quality/pollution monitoring
- water quality/pollution monitoring, including detection of chemical and micro-biological risks
- soil quality monitoring
- indoor monitoring (schools, hospitals, offices, private houses)

Greenhouse gases monitoring

Kyoto Protocol:
„The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic **carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A** do not exceed their assigned amounts…"

	Greenhouse gas (Annex A of the Kyoto Protocol)	Chem. form.	Absorption lines in MIR [μm]
1	Carbon dioxide	CO_2	4.3
2	Methane	CH_4	2.3, 3.3, 7.5
3	Nitrous oxide	N_2O	2.9, 3.9, 4.5, 7.7
4	Chlorofluorocarbons (HFCs)	CCl_xF_y	13.7
5	Perfluorocarbons (PFCs)	CF_x	7.8
6	Sulfur hexafluoride	SF_6	10.6

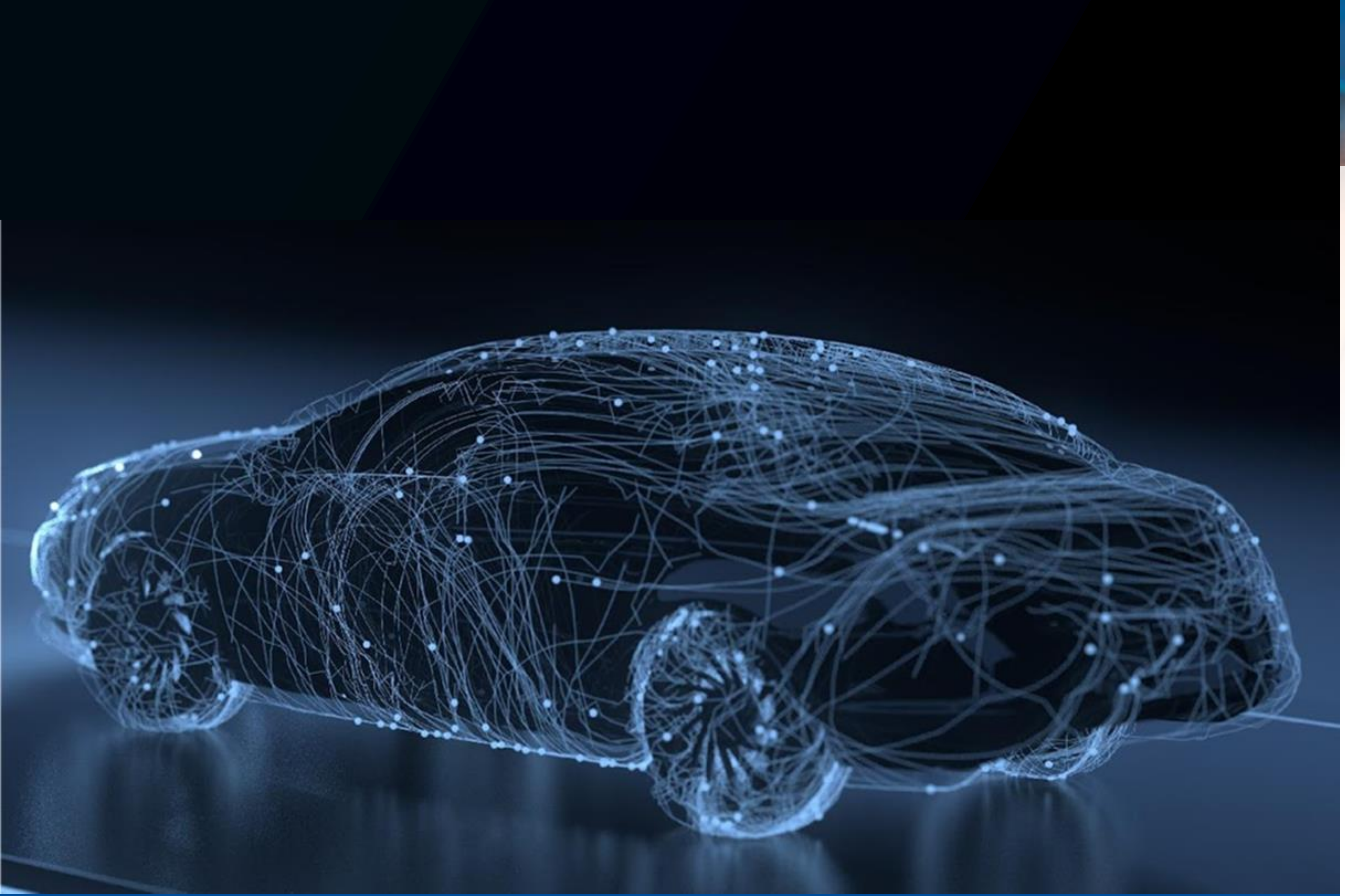
Agriculture & food industry

Growing demand for safier, healthier and higher quality food with smaller carbon footprint

- monitoring of the quality of air, water and soil
- monitoring of microorganisms in plants
- reduction of the use of fertilizers/pesticides
- prevention of soil degradation
- monitoring of food quality at every stage of production and distribution
- smart sensors for packages
- reduction of food wasting

- market growth of precision farming equipment and services from 3.3 billion USD in 2016 to 5.9 billion USD in 2021

Automotive



Autonomous motor vehicles | Advanced driver-assistance systems ADAS | Driver monitoring systems | Gesture-based control systems | Cabin monitoring (CO2, pollution, alcohol)

Constantly increasing number of sensors installed in modern cars, buses and trucks (including autonomous)

- monitoring of classical (combustion) and next generation (electric) engines
- in-cabin sensors
- advanced driver assistance systems (ADAS)
- thermographic cameras
- new generation LIDARs

- market growth additionally stimulated by new EU regulations
- market volume up to tens of million of units per year

Medical

Photonics provides vital components to medical technologies for the instant diagnosis of major diseases...

- breath analysis (O_2, CO_2, NO, H_2S, NH_3 and other gases, inflammation and cancer markers)
- body fluids analysis
- sweat analysis

- mobile and wearable biosensors
- smart health systems
- contactless monitoring of infants/elderly people

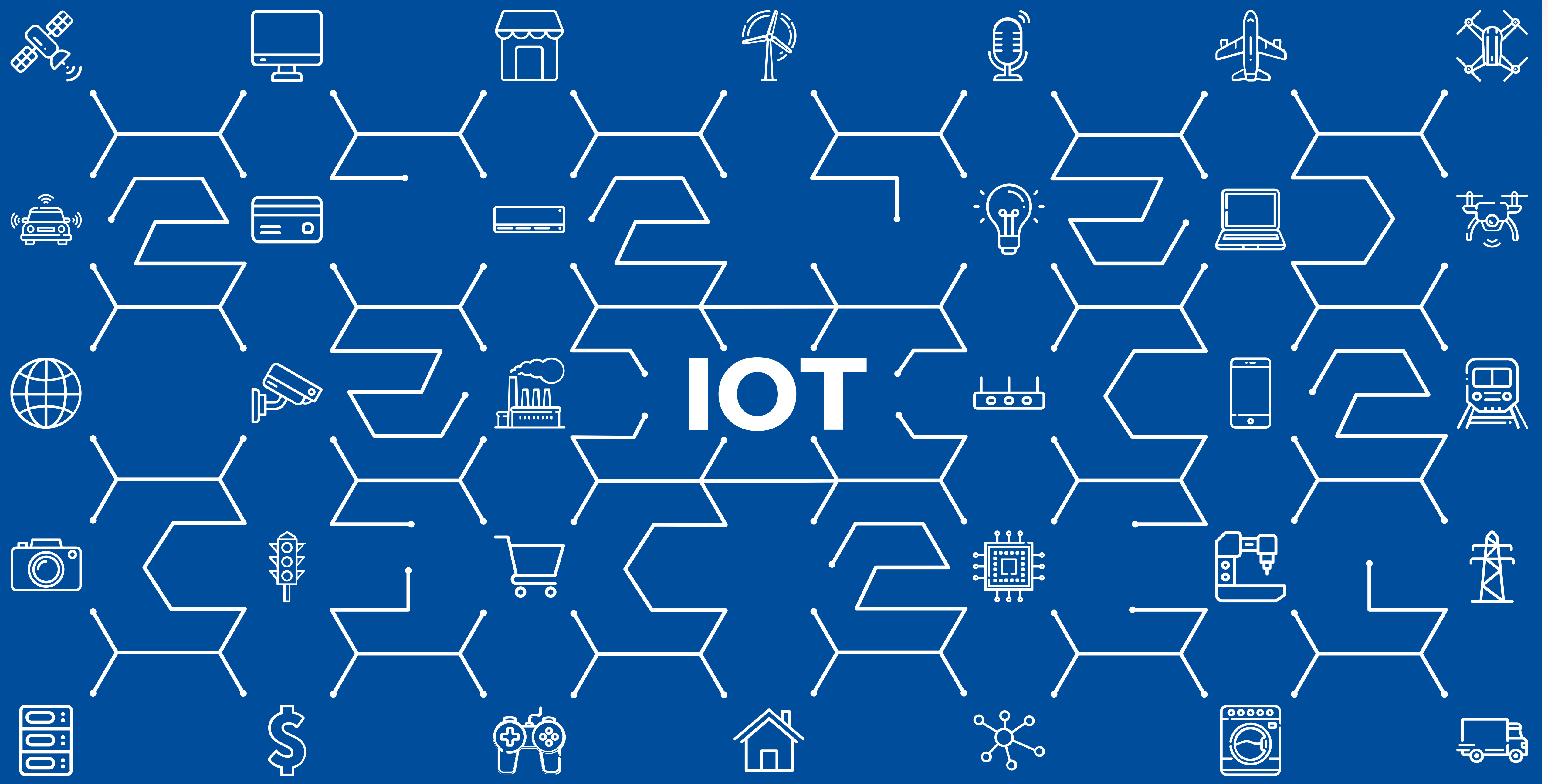
- nearly 10% of European GDP in 2021
- photonics in healthcare is assumed to reach 50 billion EUR worldwide
- a rapidly expanding sector

Security and Safety

Growing demand for fast and contactless detection of potential threats to people and critical infrastructure

- detection of explosive materials
- detection of toxic and flammable gases
- detection of drugs and other prohibited chemicals
- chemical & microbiological contaminations
- testing and analysis of biological and chemical samples
- identification of silent virus carriers
- food security

Internet of Things



Billions of physical devices around the world connected to the internet

- indoor monitoring - public offices/private houses (air/water quality/contamination)
- home appliance sensors (gas/liquid analysis)
- furnace monitoring in private houses (CO_2, CO, SO_2)
- mobile/wearable sensors (medicine, sports)
- industrial processing monitoring
- large-area sensor networks in cities

A rapidly expanding sector, 6300 IoT start-ups in May 2020 (globally), prediction of up 75 bilion devices installed by 2025*

MIR photonics in Poland

VIGO PHOTONICS

Epiwafers

Infrared photon detectors

Infrared detection modules

VIGO Photonics S.A. is a **photonic semiconductors** company.

The sole European provider of photon mid-infrared detectors, competing with Asian and US companies.

Manufacturer of **high-quality epi-wafers for photonic and microelectronic** applications based on advanced compound materials (III-V & II-VI).

On the road to **Mid-IR Photonic Integrated Circuits foundry**

35
YEARS ON THE MARKET

220
EMPLOYEES

6500 m²
PRODUCTION AREA

6
DETECTORS ON MARS

MIRPIC technology platform

MIRPIC

PHOTONIC INTEGRATED CIRCUITS TECHNOLOGIES FOR MID INFRARED

VIGO PHOTONICS

Łukasiewicz IMiF

POLITECHNIKA WARSZAWSKA WARSAW UNIVERSITY OF TECHNOLOGY

started in April 2021

AIM

Development of the technology of manufacturing application-specific photonic integrated circuits (ASPIC) for MIR spectral range, providing the foundation for the first Polish PICs foundry

- **product innovation** – unique ASPICs for MIR spectra range (3.0-5.5 µm)
- **know-how** – design, development, and integration of fundamental building blocks, mastering key technologies
- **solid foundation** for the first Polish PICs foundry

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NCBR Narodowe Centrum Badań i Rozwoju

Project financed by the National Centre for Research and Development in the frame of a strategic programme of scientific research „Modern materials' technologies" - TECHMATSTRATEG III.

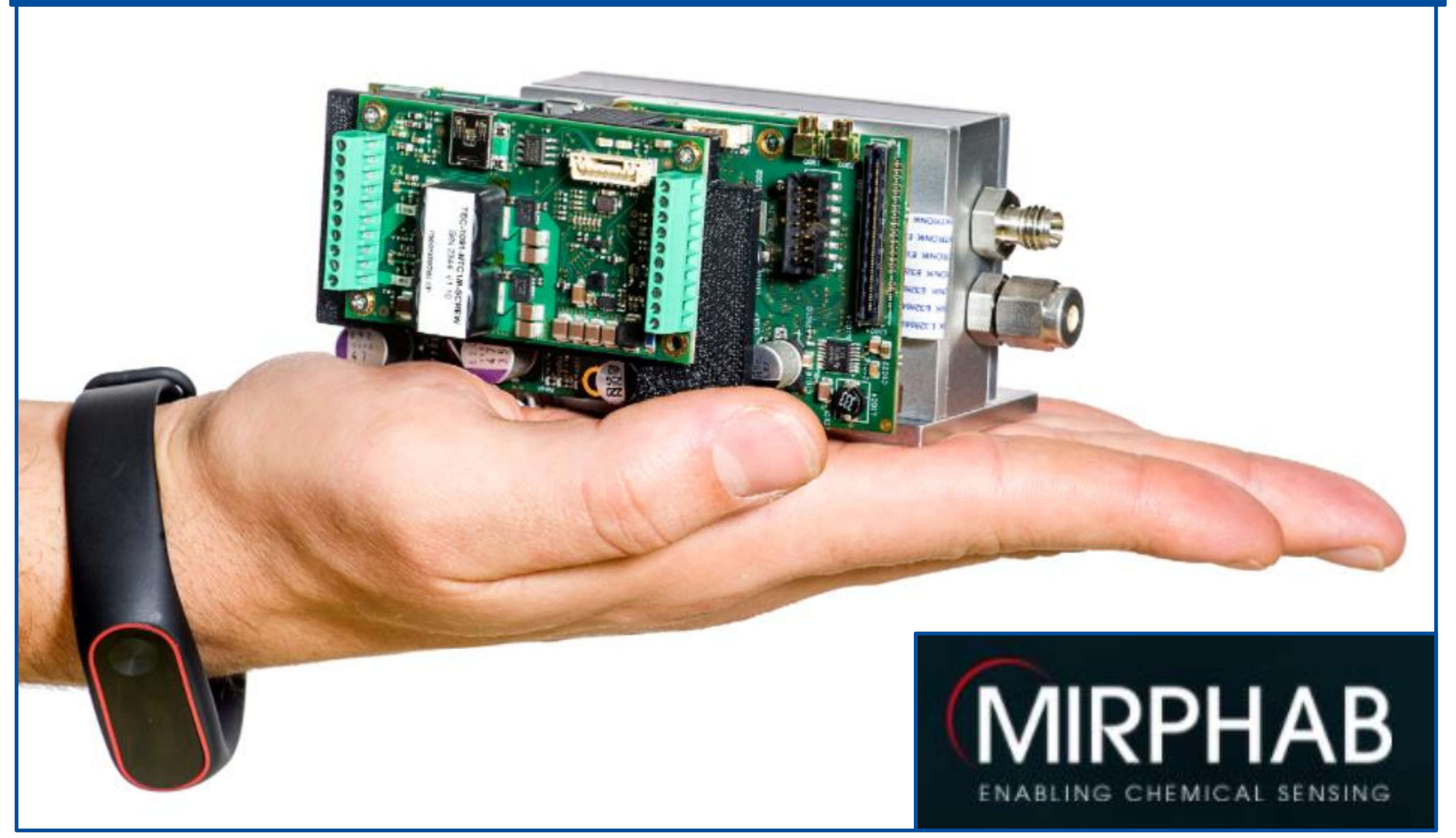
Rzeczpospolita Polska

MIRPIC technology platform

yesterday

THE KEY ELEMENT of VIGO Photonics STRATEGY!

today



tomorrow

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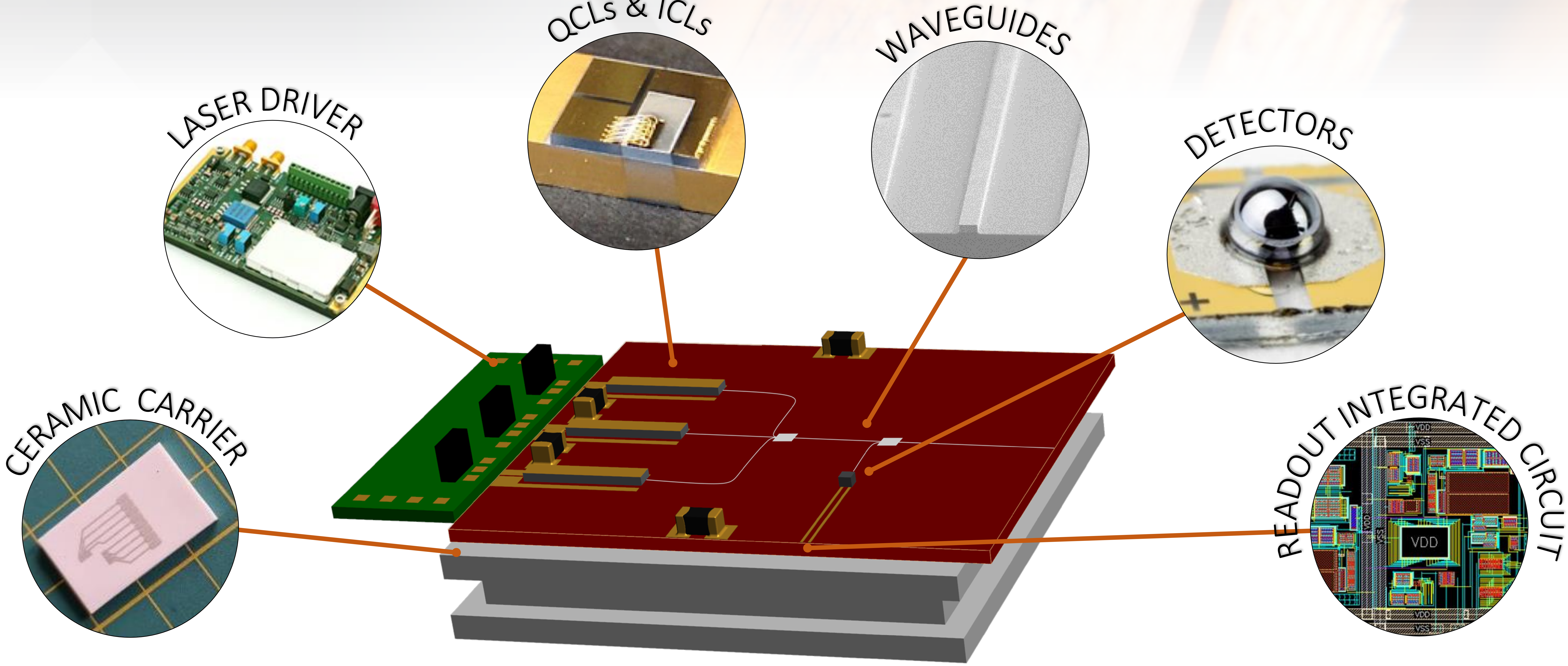
MIRPIC technology platform



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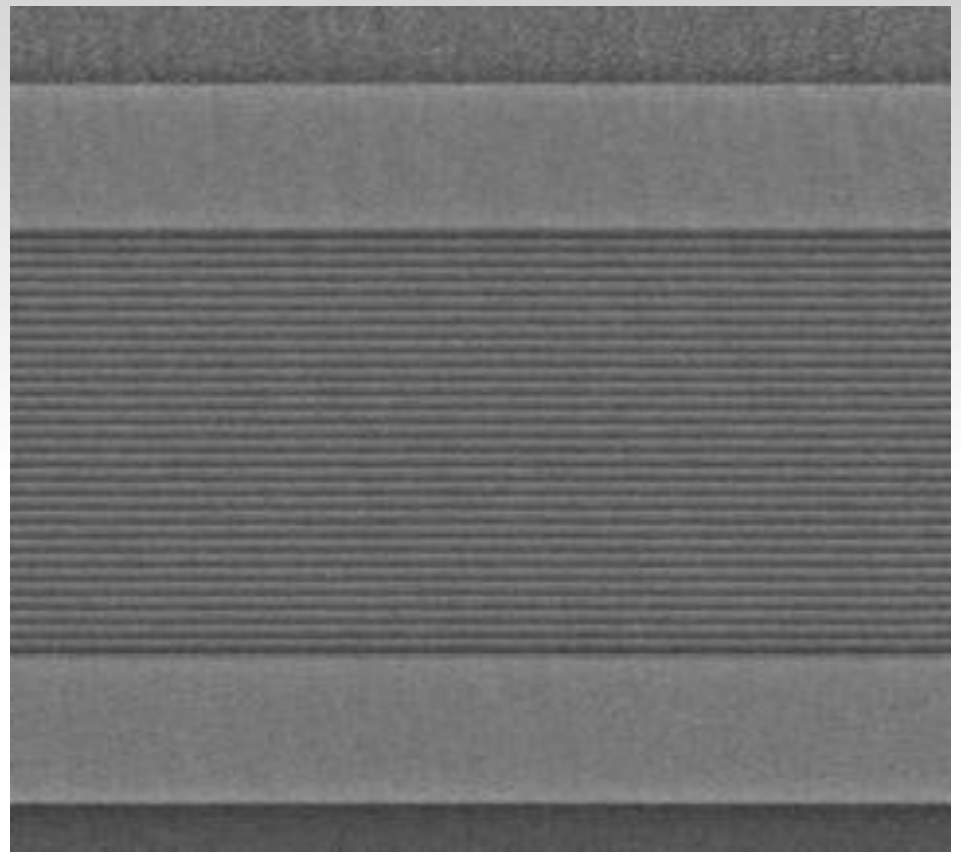
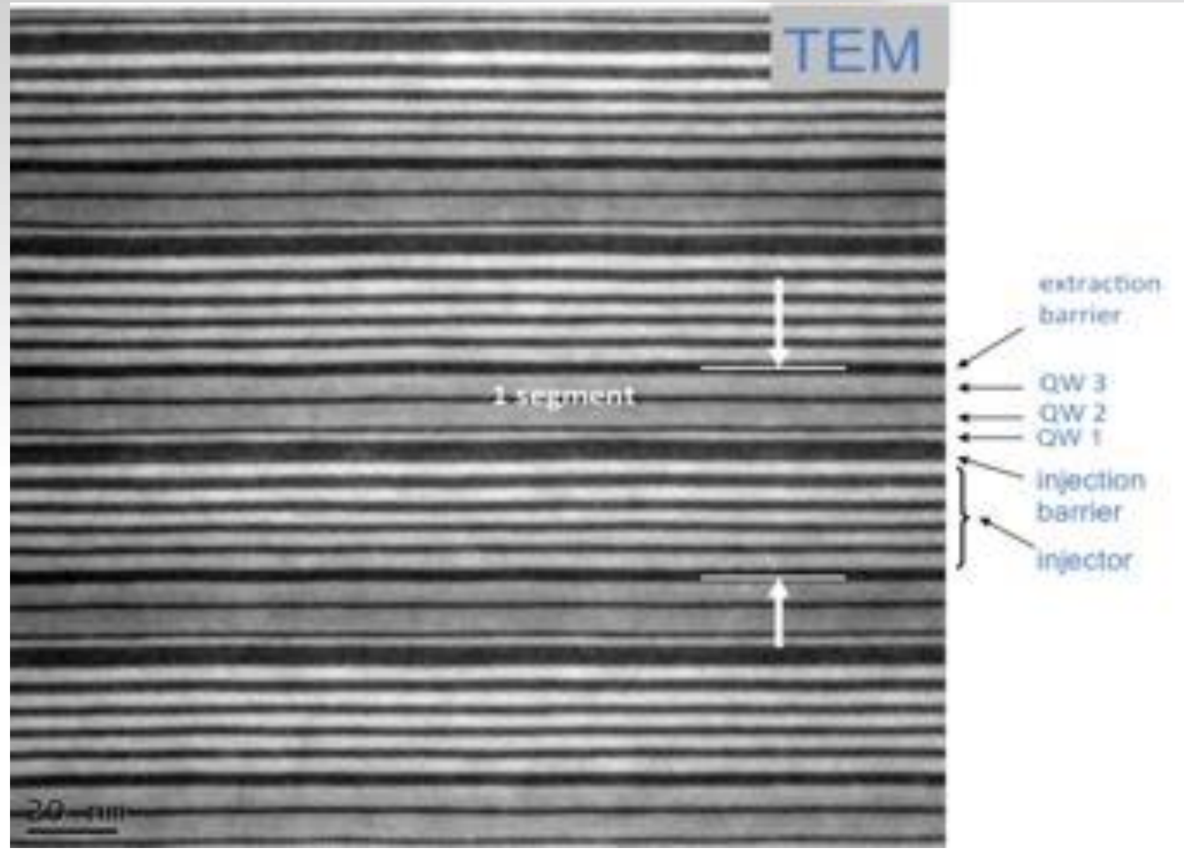
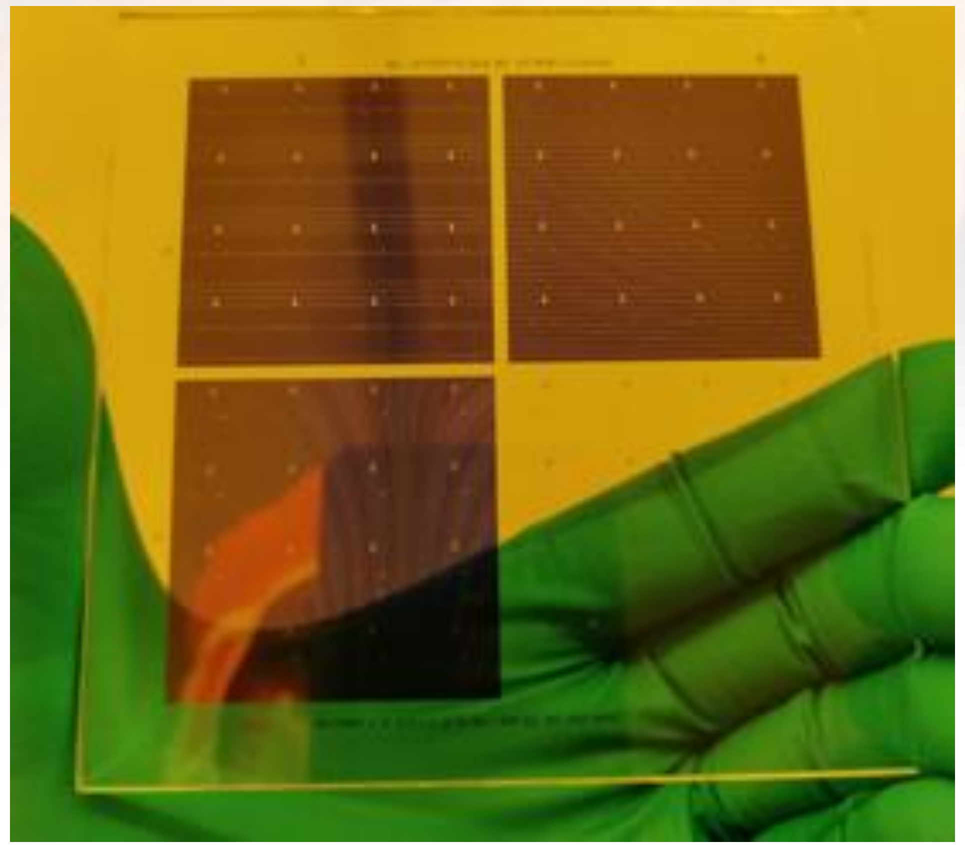
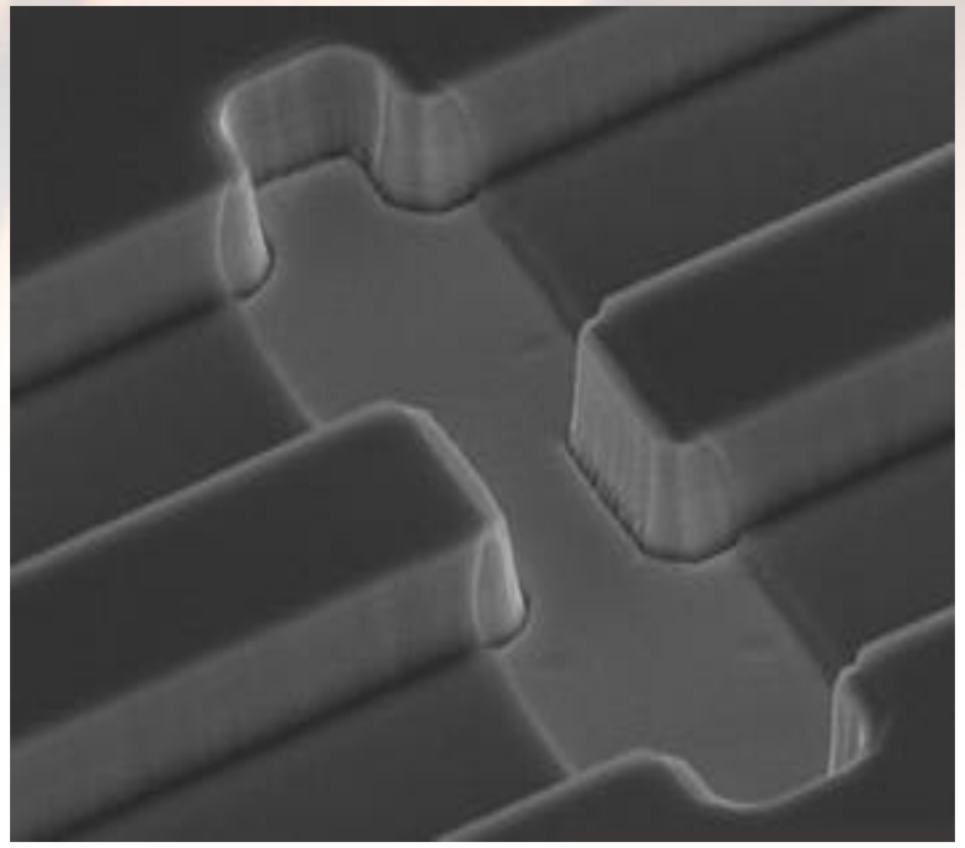
Light sources - QCLs



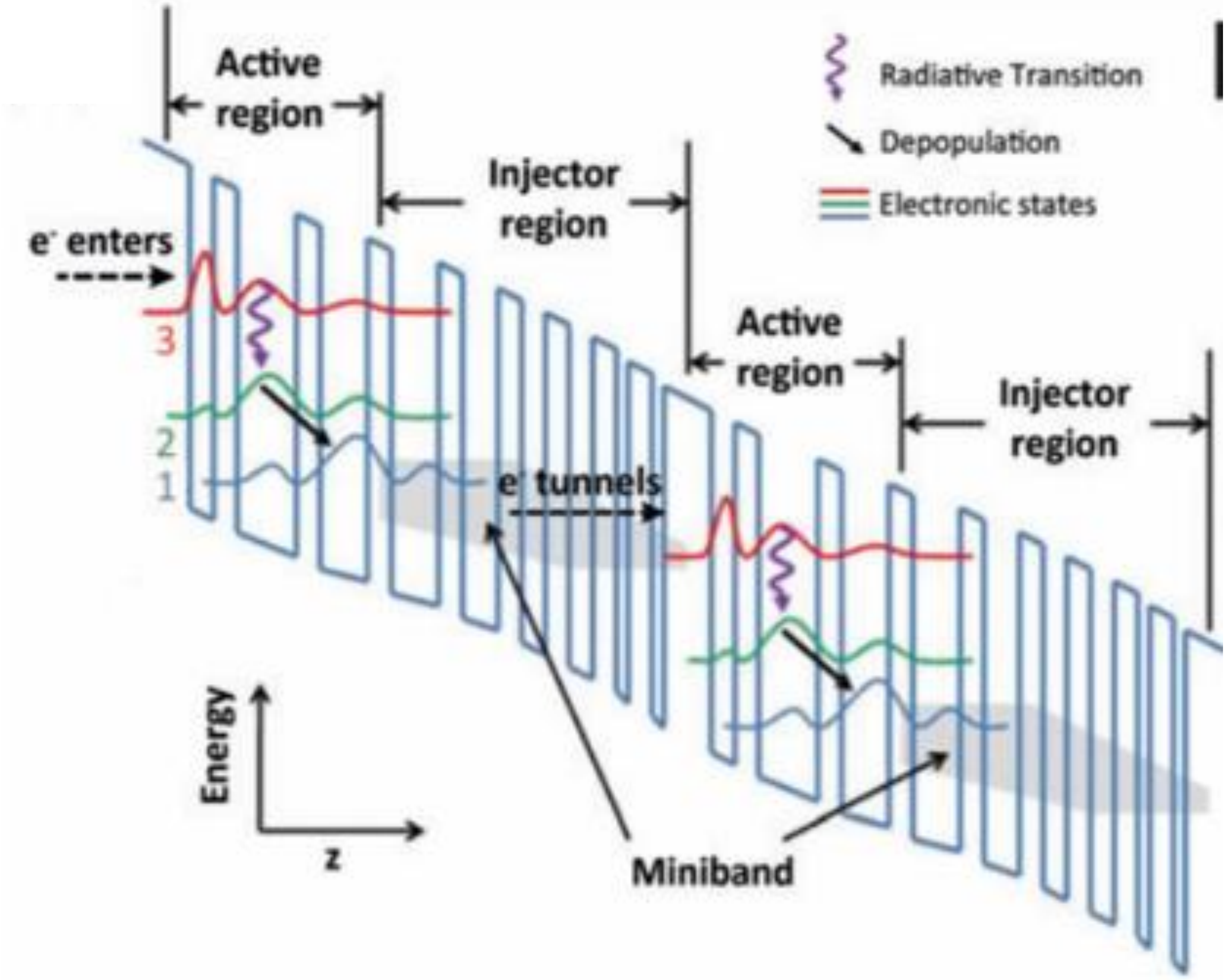


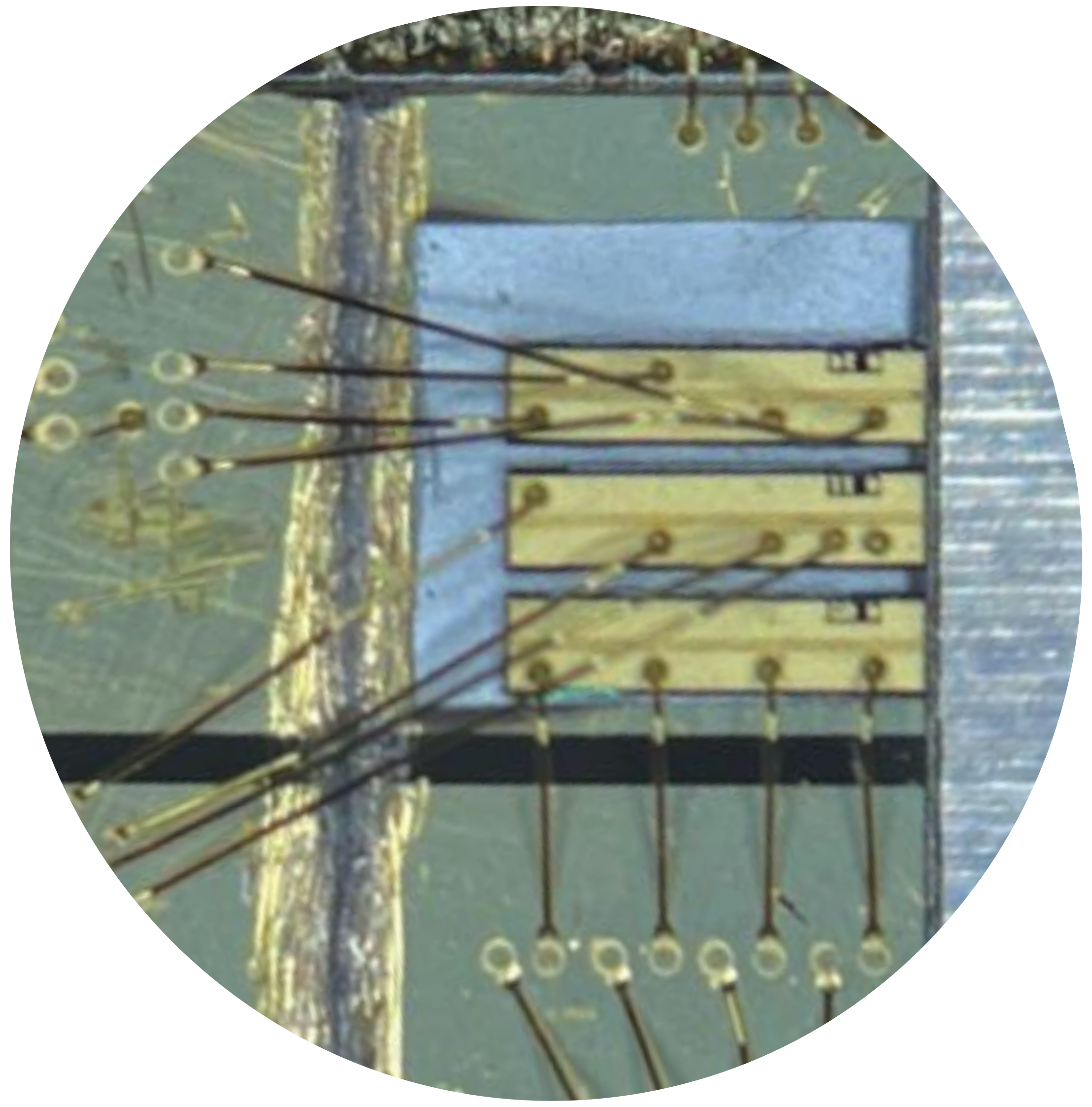




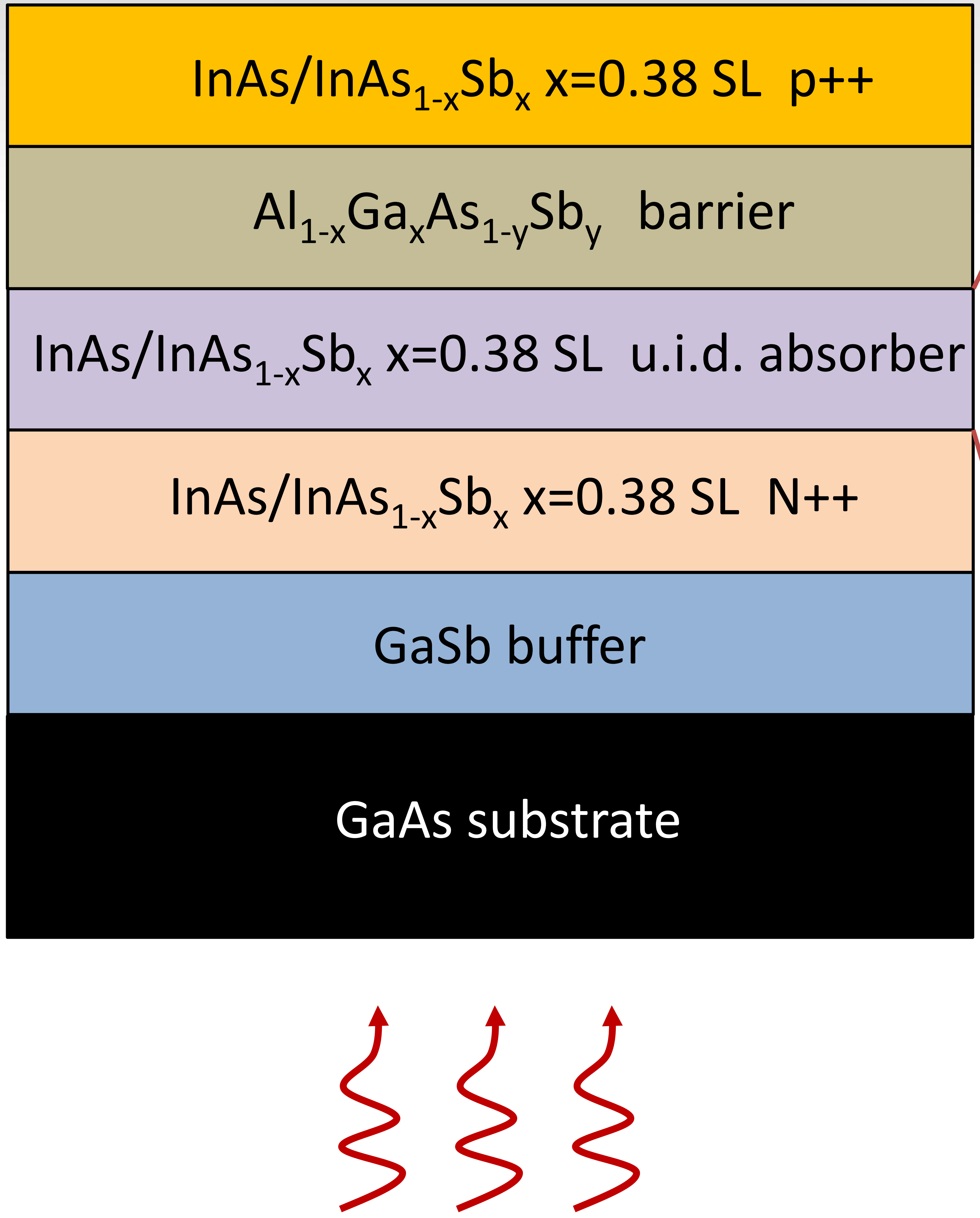
growth technology

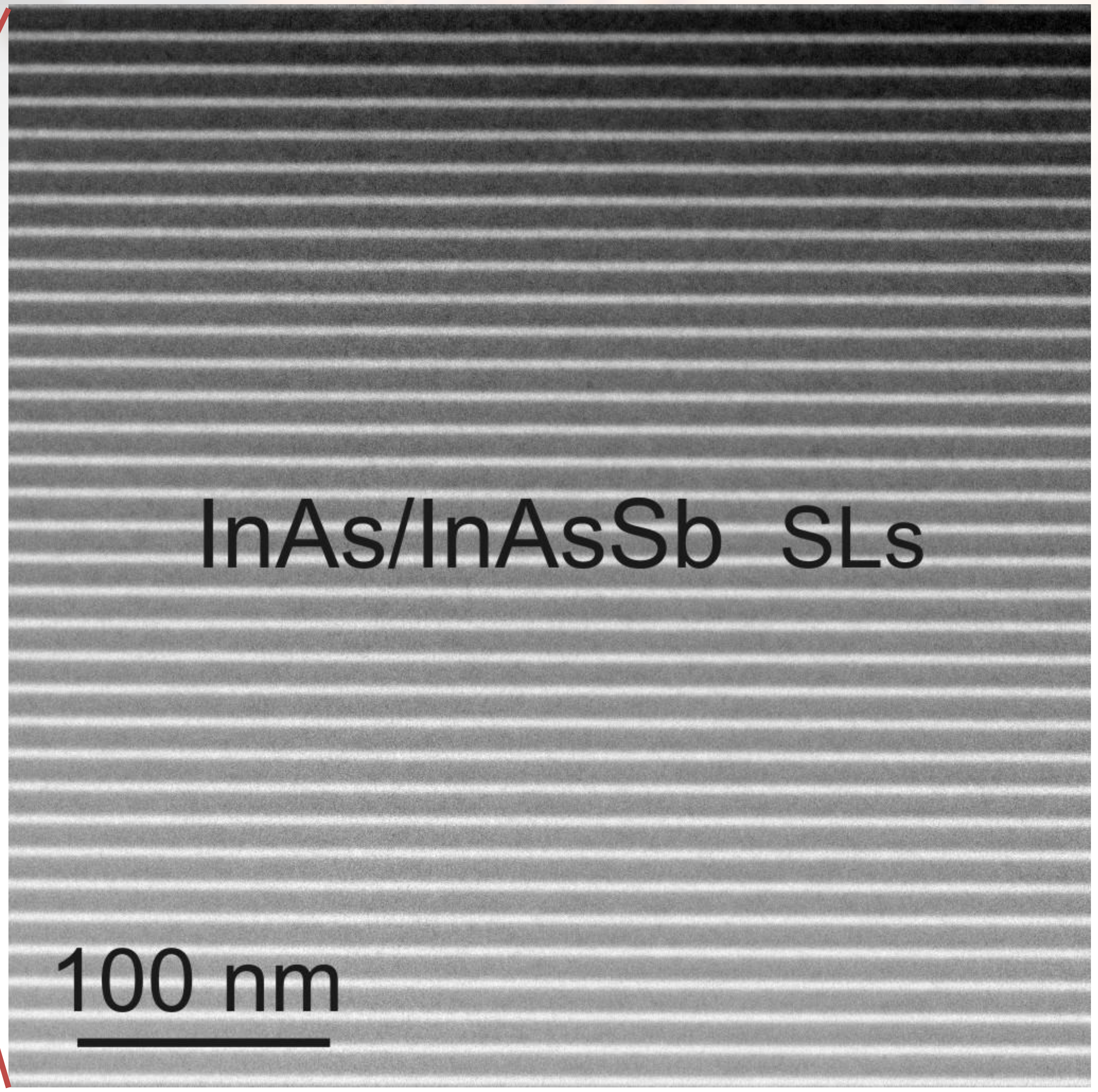
processing technology

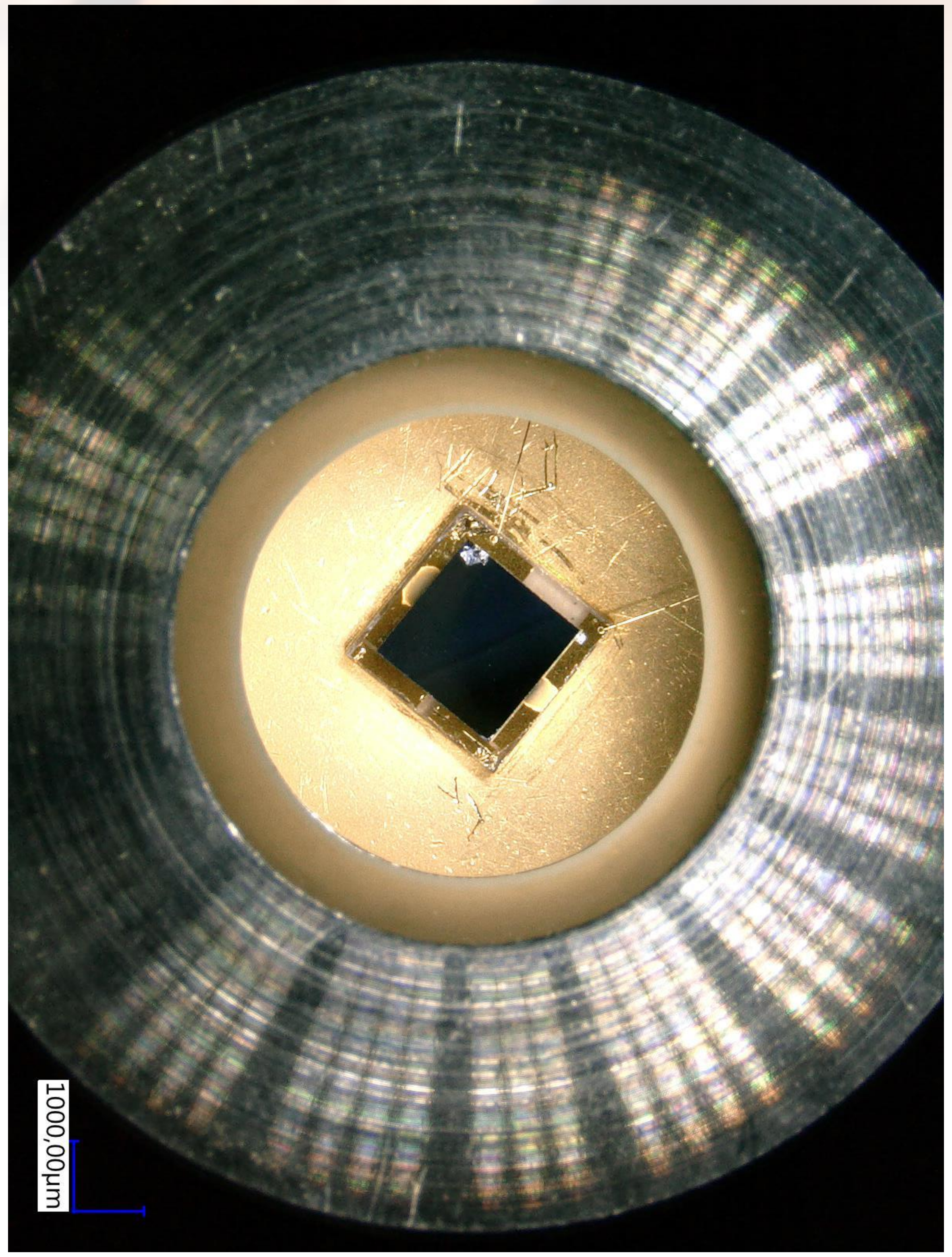




Detectors – antimonide super-lattice







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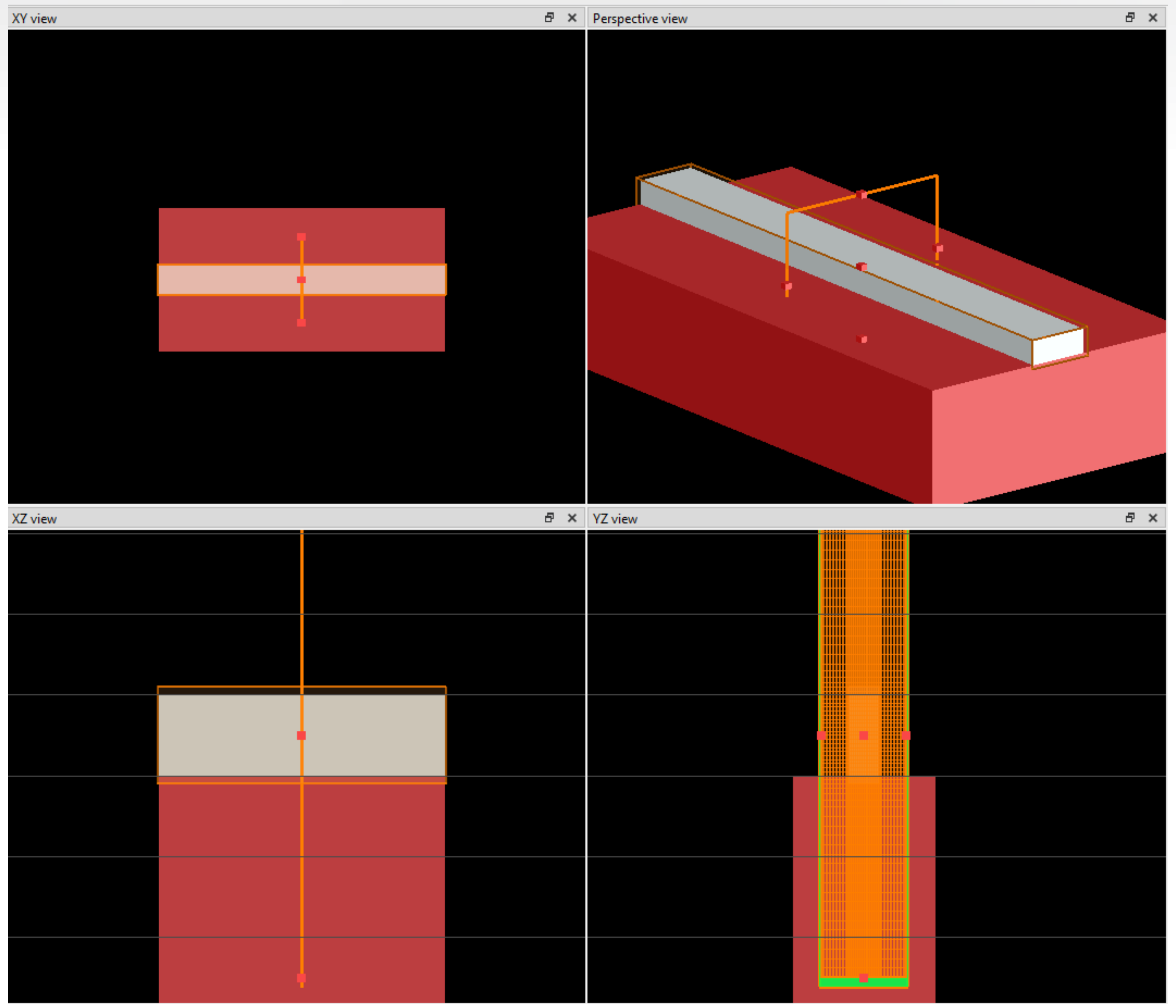
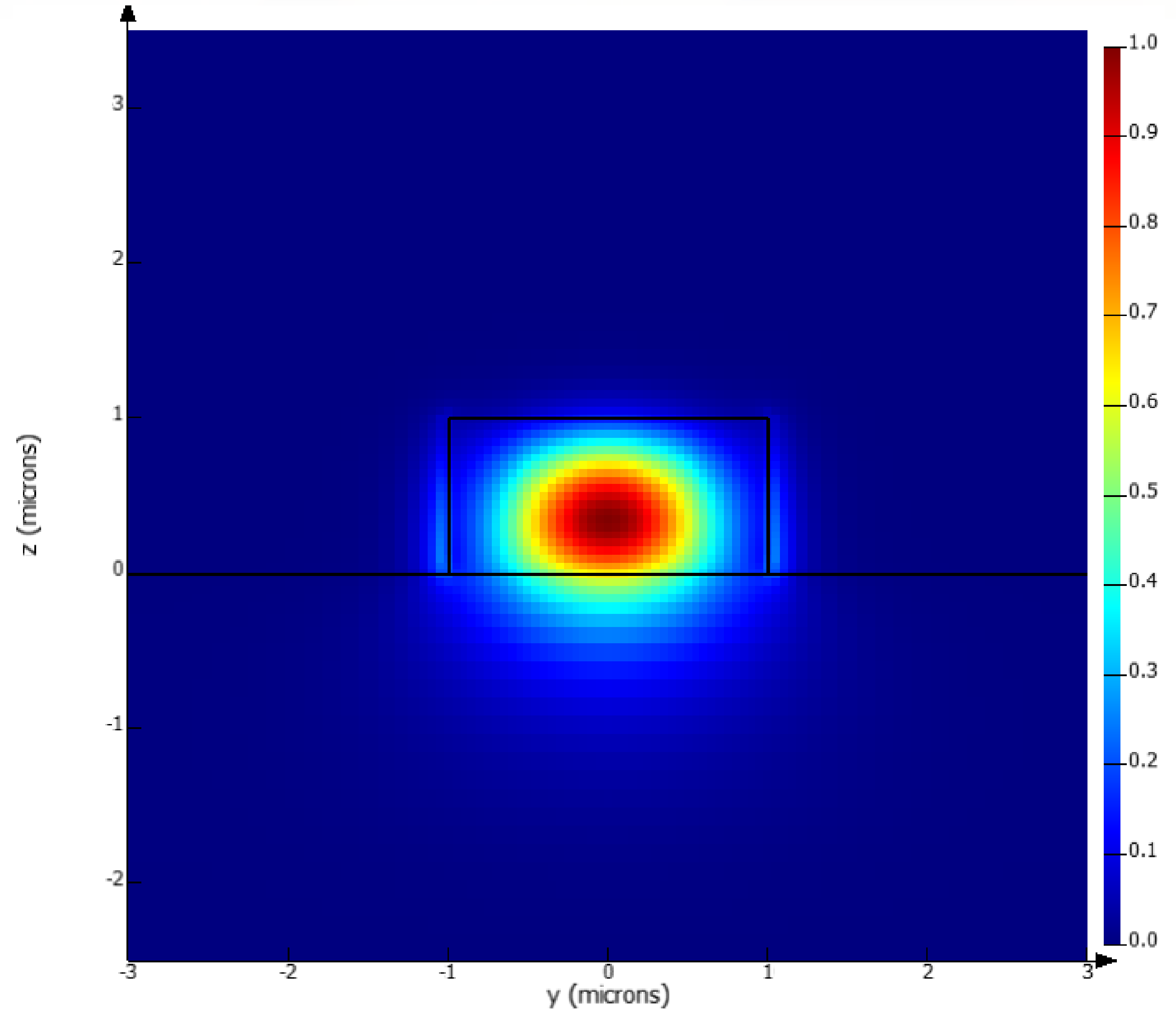
Ge-on-Si technology – modeling of passive waveguides



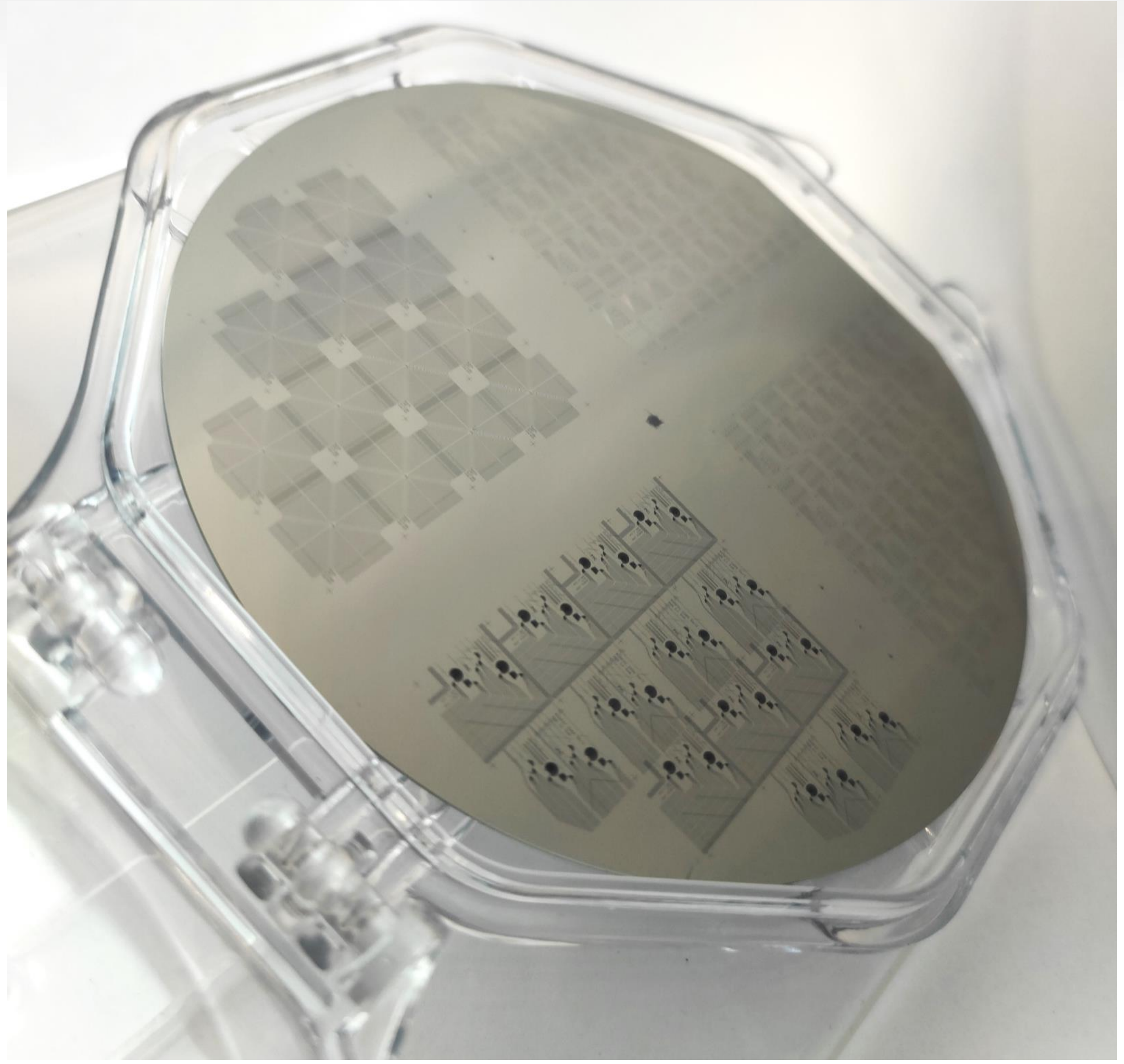
λ = 5.5 µm
W = 2 µm
d = 1 µm

TE fundamental mode

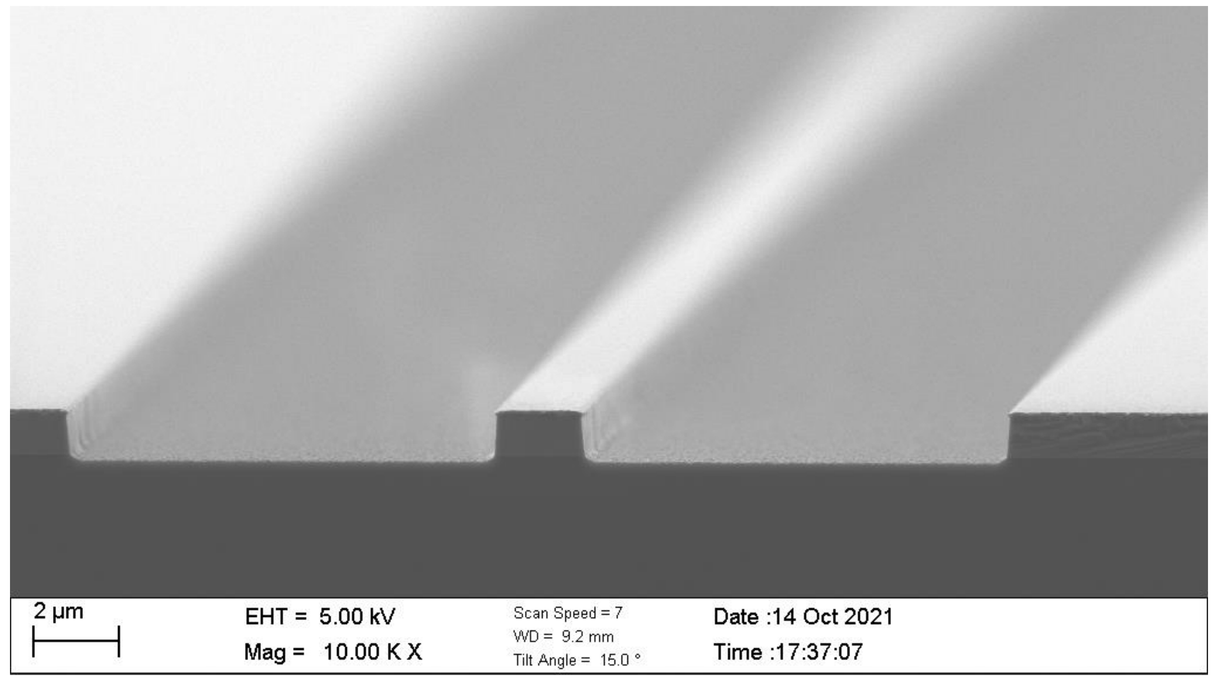


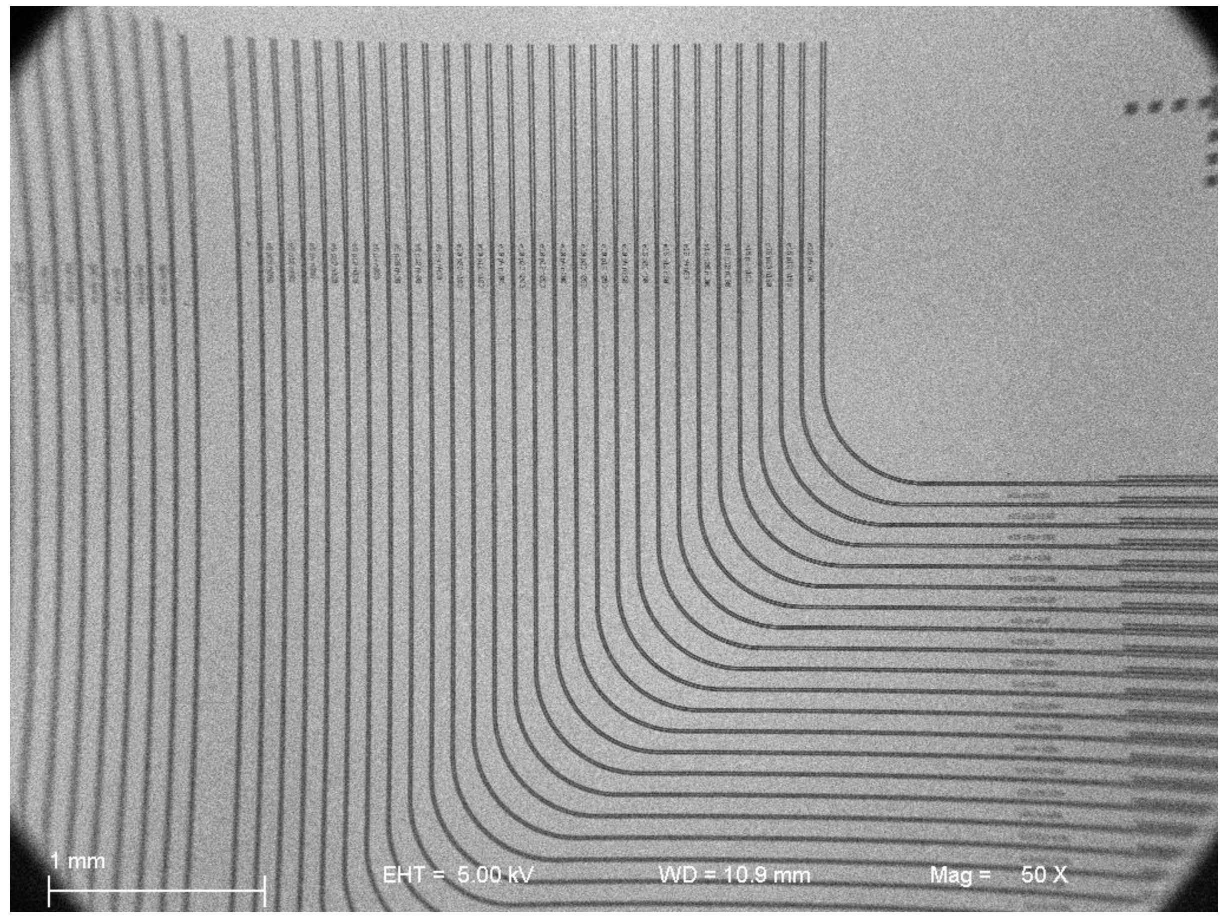
d = 1 µm	TM0 or TE0	TM0 + TE0	Multimode
W [µm] for λ = 3.0 µm	0.7 – 0.9	0.9 – 1.5	> 1.50
W [µm] for λ = 5.5 µm	1.8 – 2.2	2.2 – 3.8	> 3.80

Ge-on-Si technology – waveguides and waveguiding components

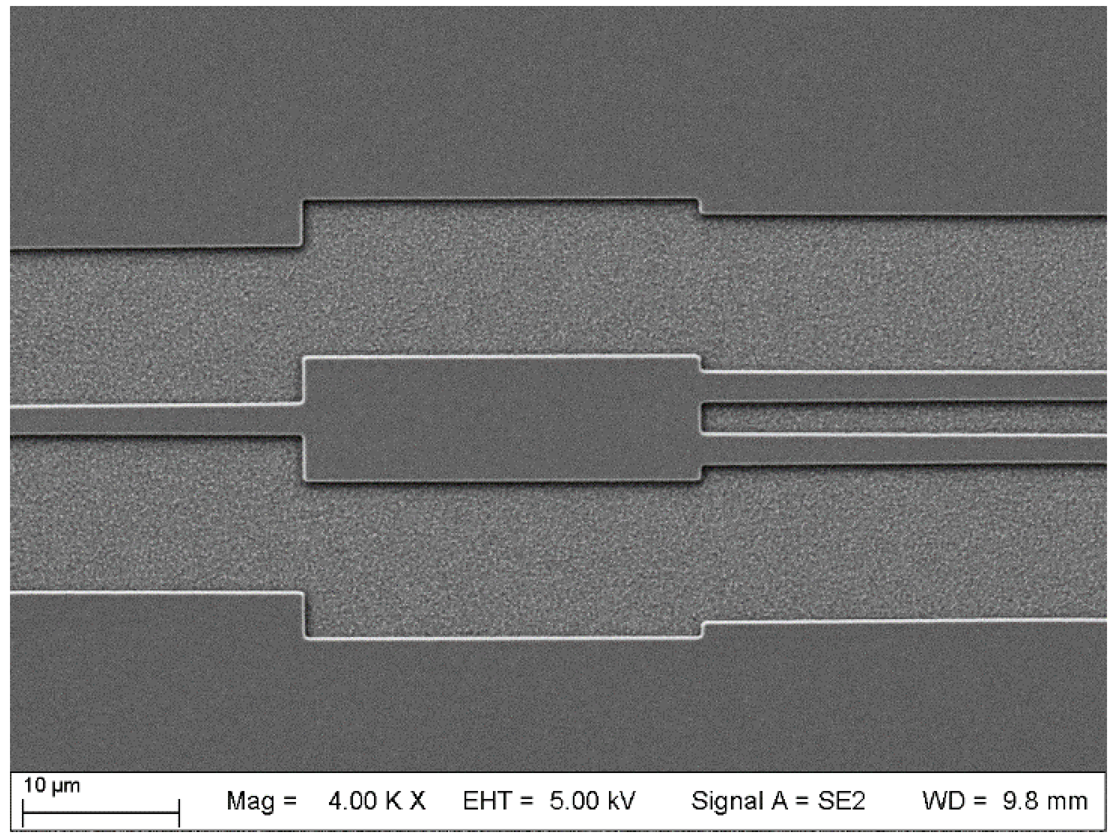


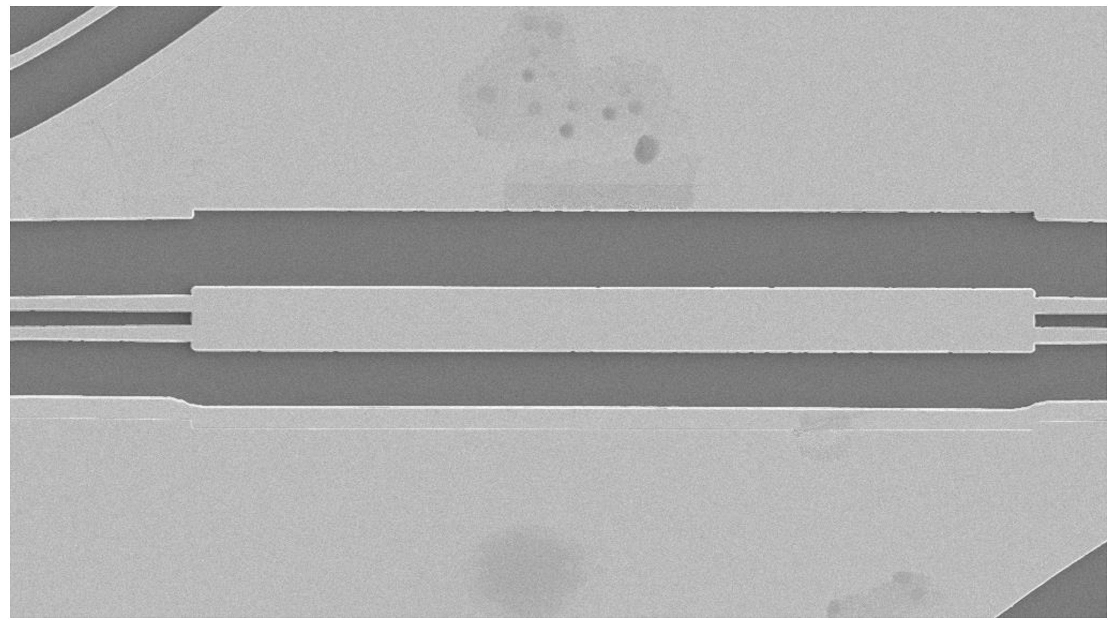
Waveguides, tapers and bends





Multi-mode interference (MMI) couplers





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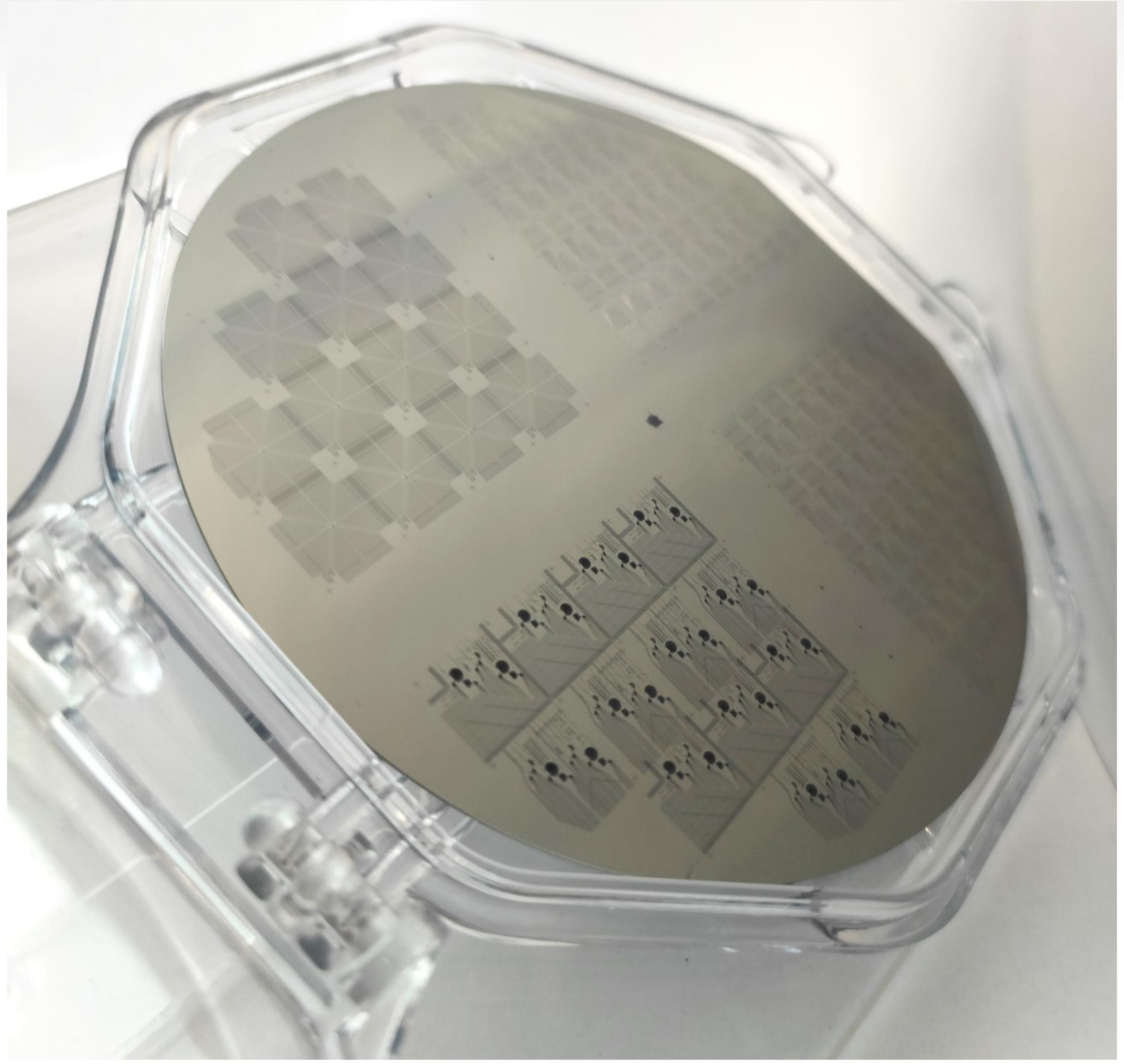
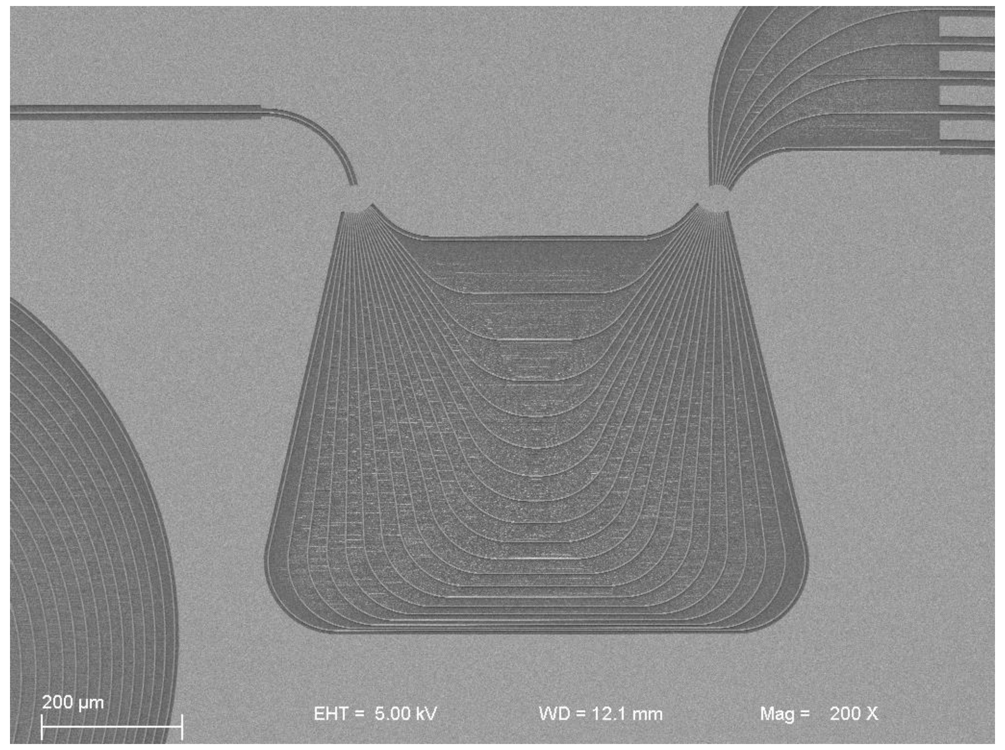
IMiO

Centre for Advanced Materials and Technologies CEZAMAT
Warsaw University of Technology

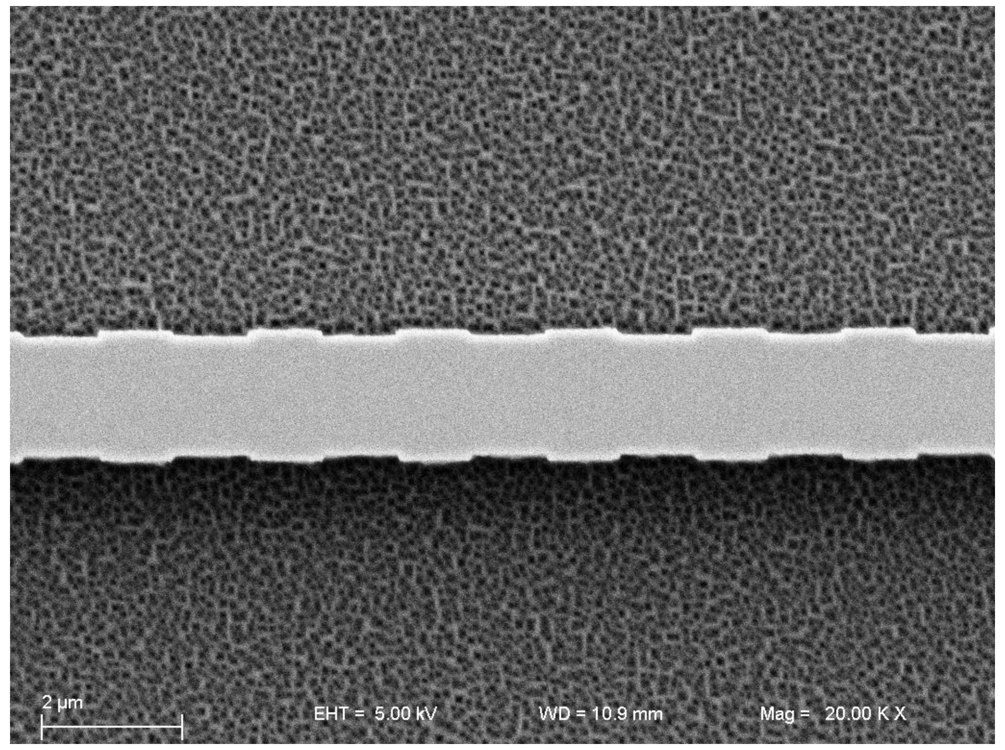
Ge-on-Si technology – waveguides and waveguiding components



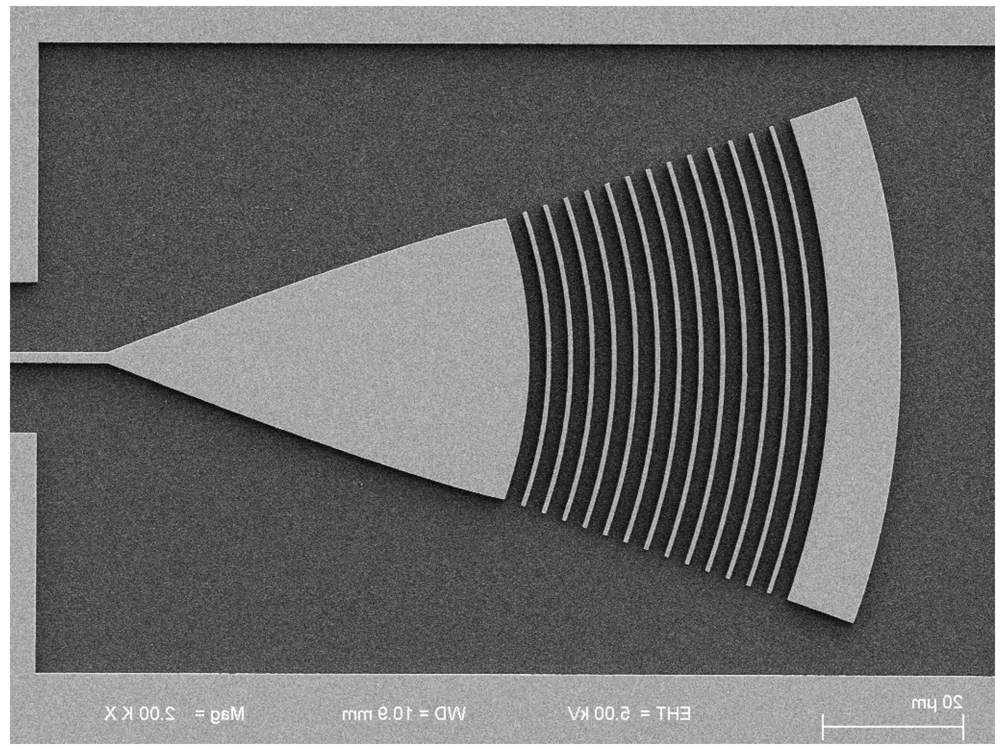
Arrayed waveguide gratings (AWG)

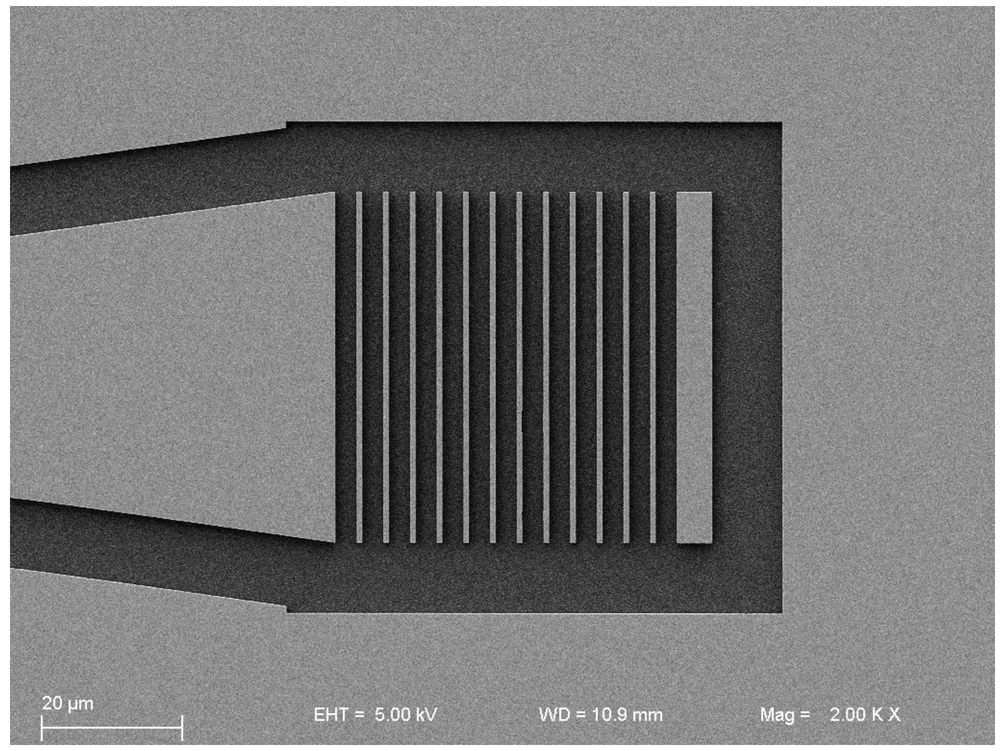


Distributed Bragg reflectors (DBR)

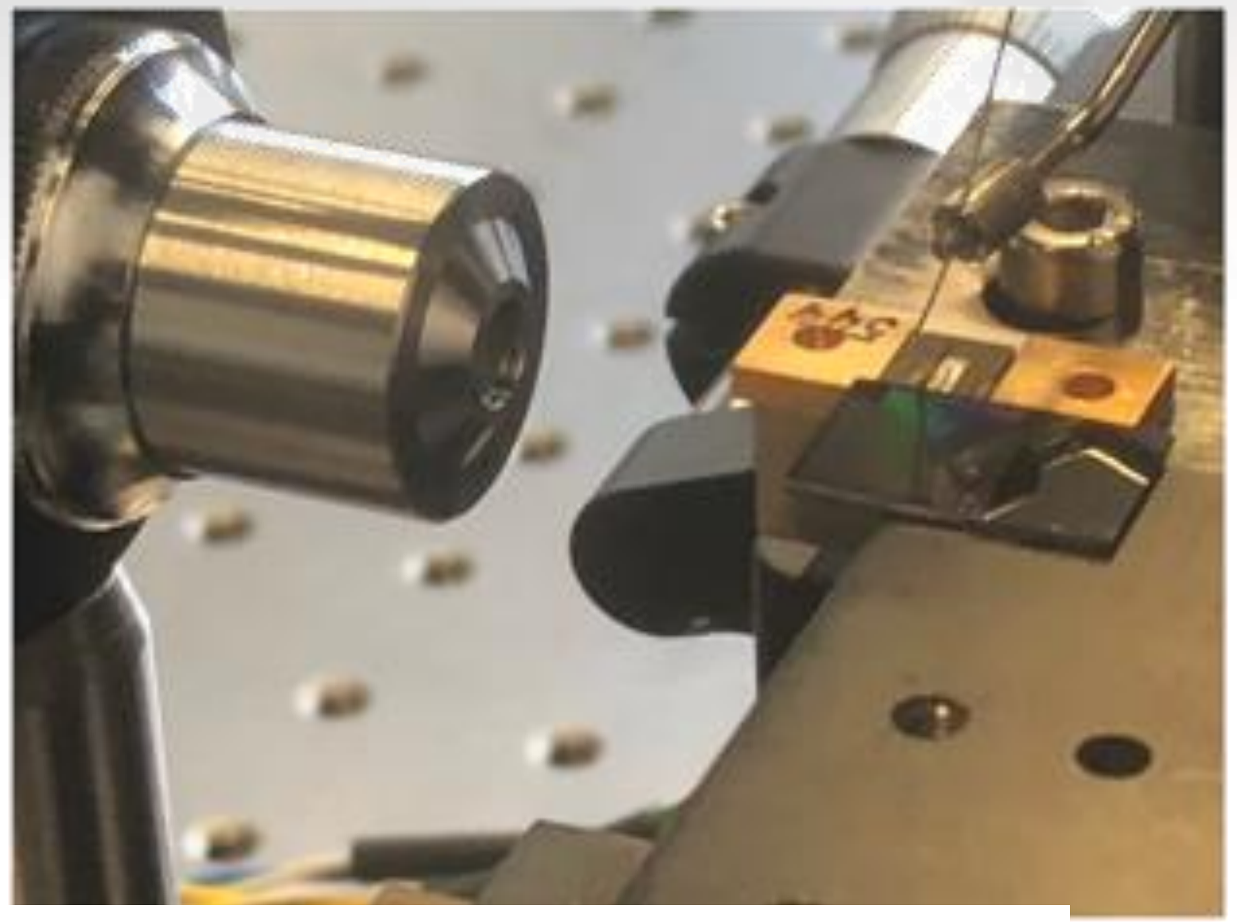


Grating couplers

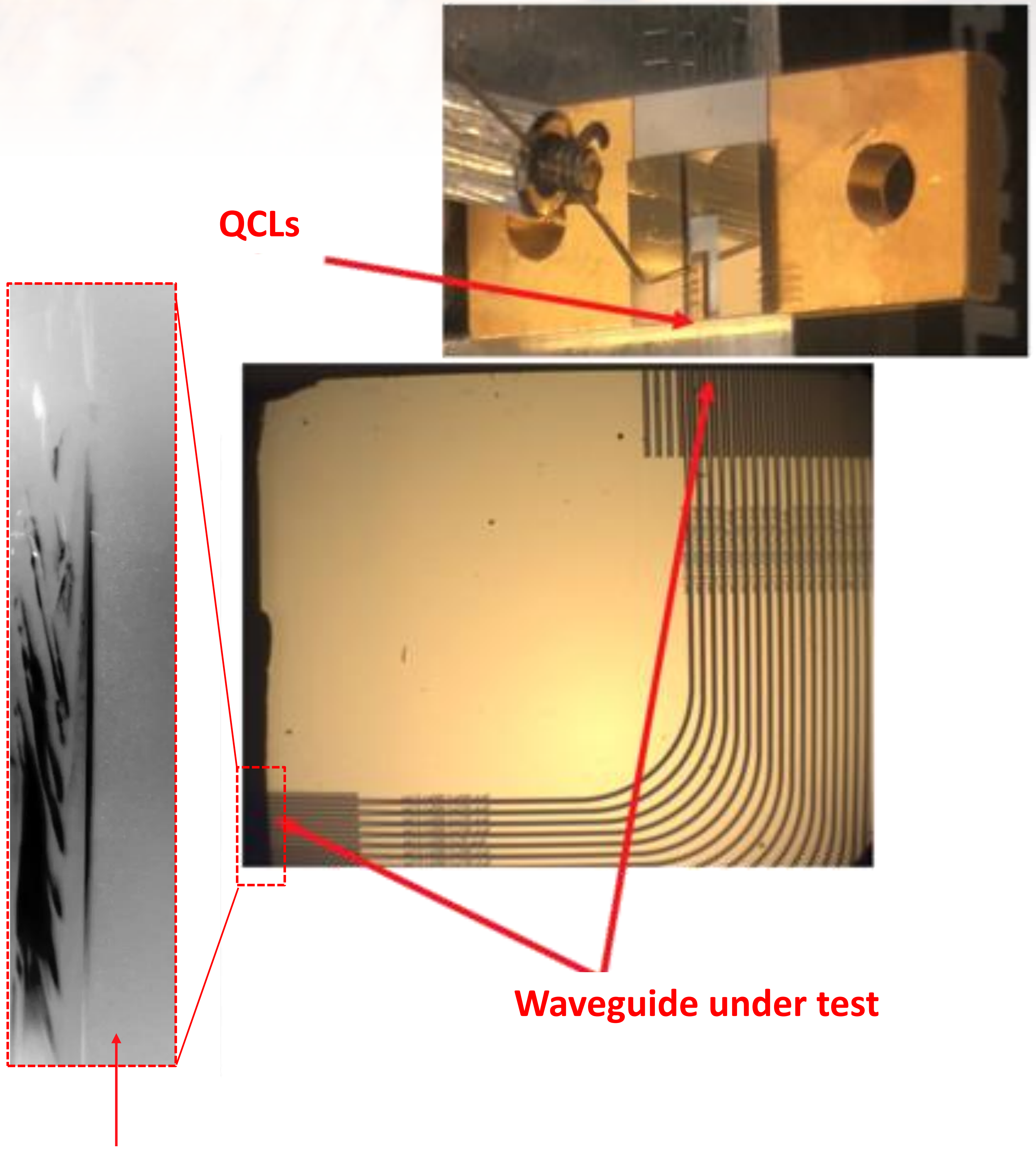




Coupling QCL lasers with germanium waveguides - first trials



Measurement setup



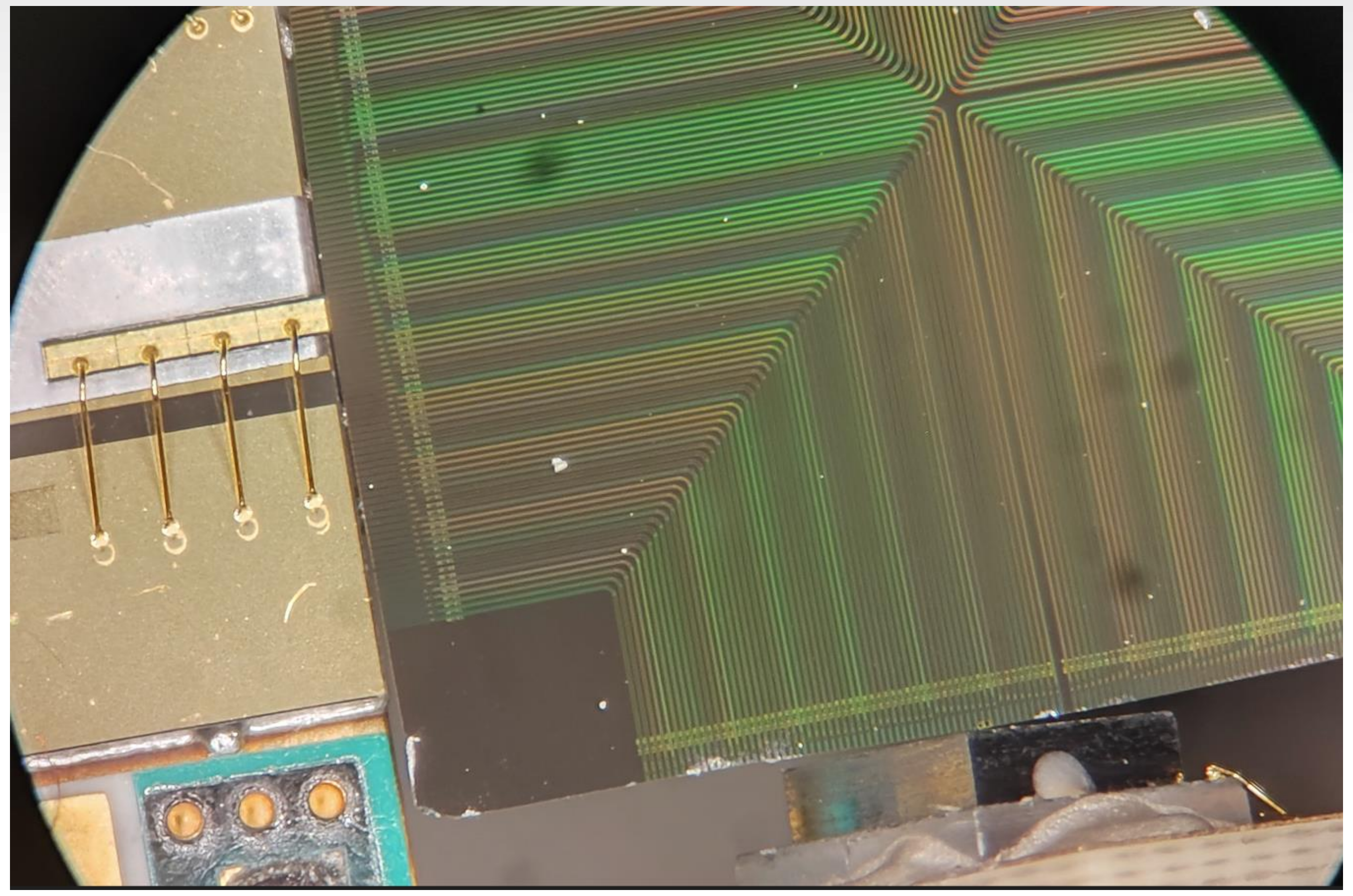
Confirmed signal transmission

$\lambda_1 = 4.7\ \mu m$

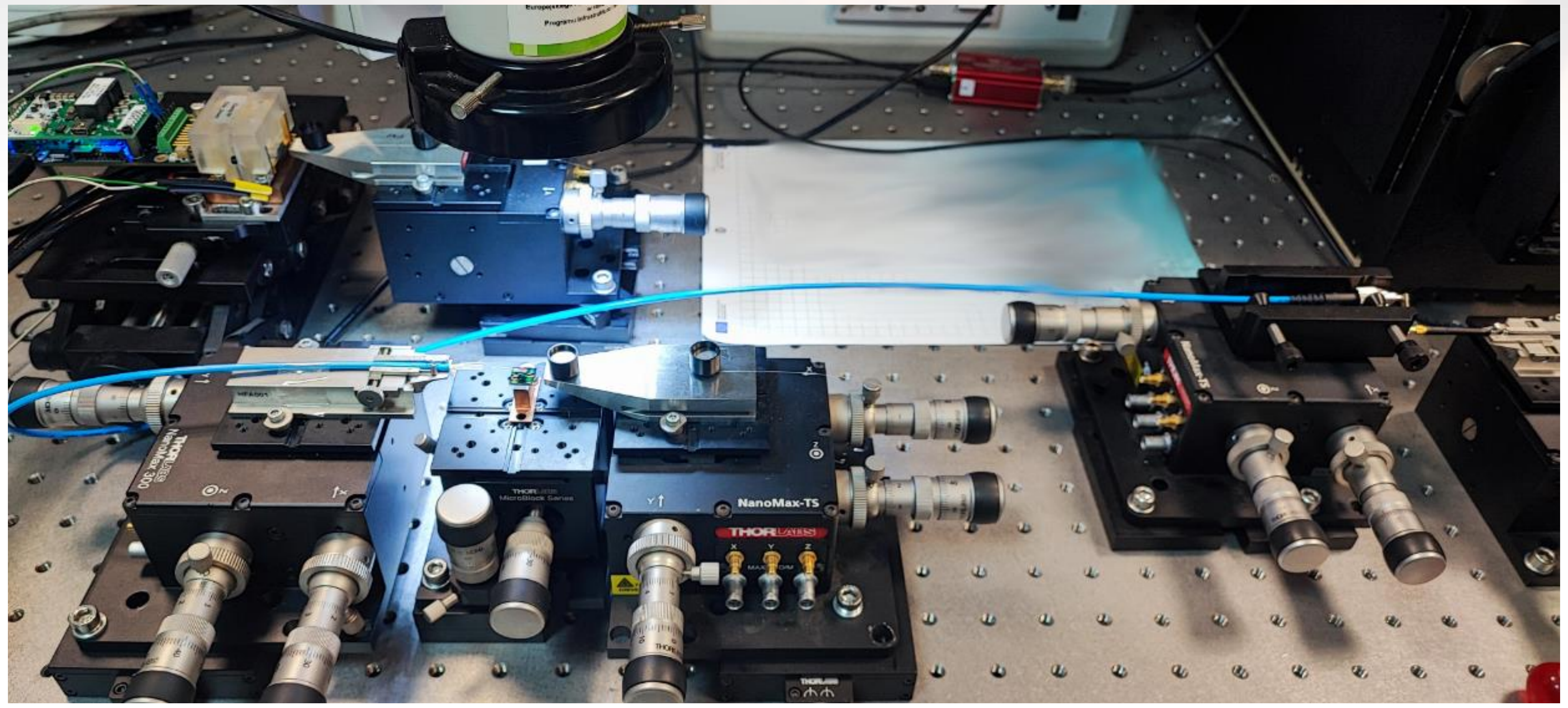
$\lambda_2 = 5.2\ \mu m$

Waveguides – germanium

Ge-on-Si technology – characterization of waveguides and passive components



Characterization setup I
Light source: QCLs (3.7 - 5.2 µm)
Detector: InAs/InAsSb superlattice
Direct butt-coupling



Characterization setup II
Light source: QCLs (3.7 - 5.2 µm)
Detector: InAs/InAsSb superlattice
Coupling through InF_3/ZBLAN single-mode and multi-mode fibers

Waveguide attenuation below 3.0 dB/cm!

Ge-on-Si material platform; waveguides H = 2.0 µm, W = 1.6 µm		
Bending radius [µm]	**Attenuation [dB/cm] (number of measurements)**	**Attenuation [dB/ 90° bend] (number of measurements)**
100	2.79 ± 0.57 (10)	0.13 ± 0.09 (8)
200	2.52 ± 0.11 (8)	0.17 ± 0.09 (10)
300	2.52 ± 0.16 (20)	0.39 ± 0.08 (19)
500	2.11 ± 0.46 (11)	0.17 ± 0.10 (14)

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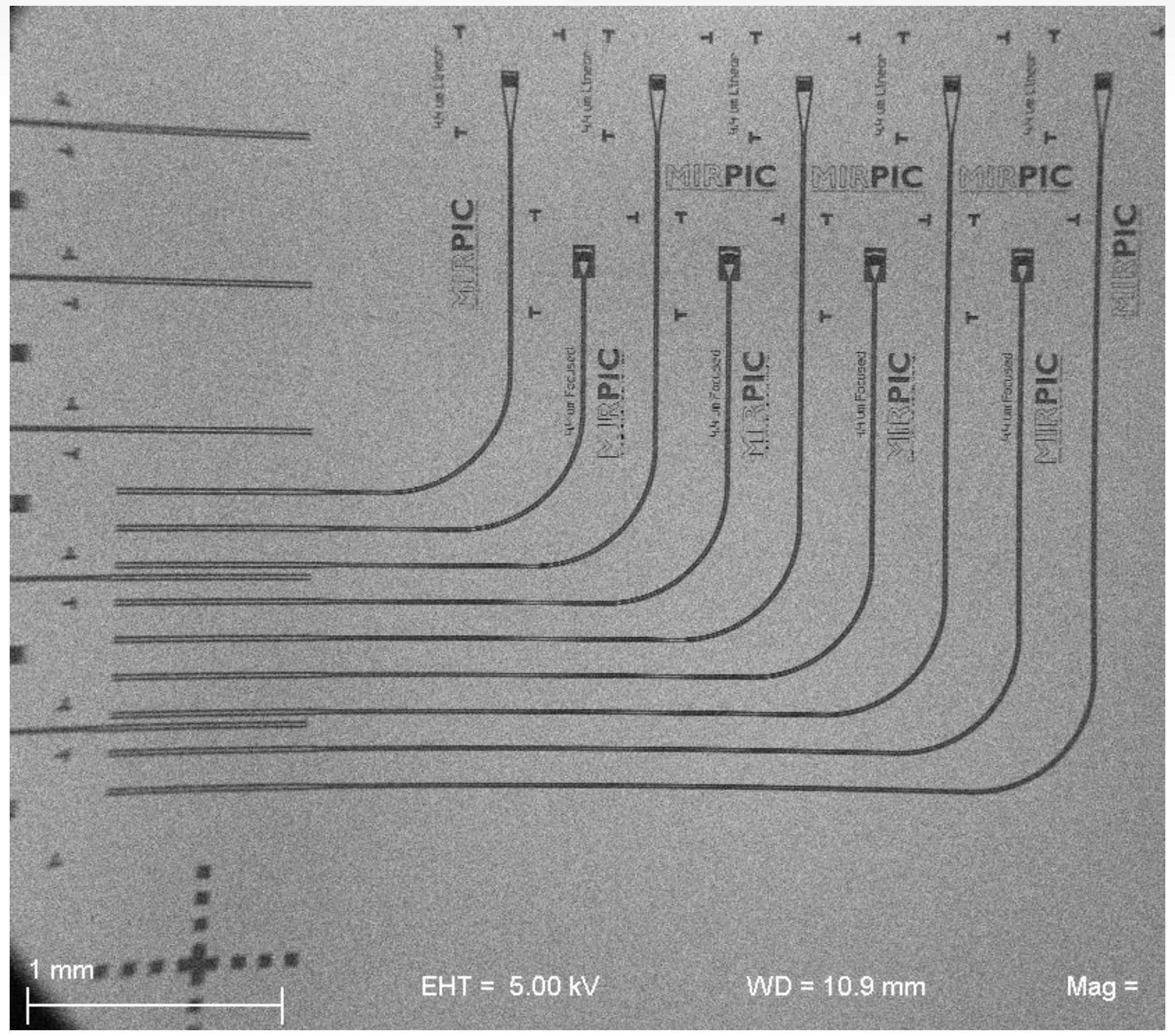
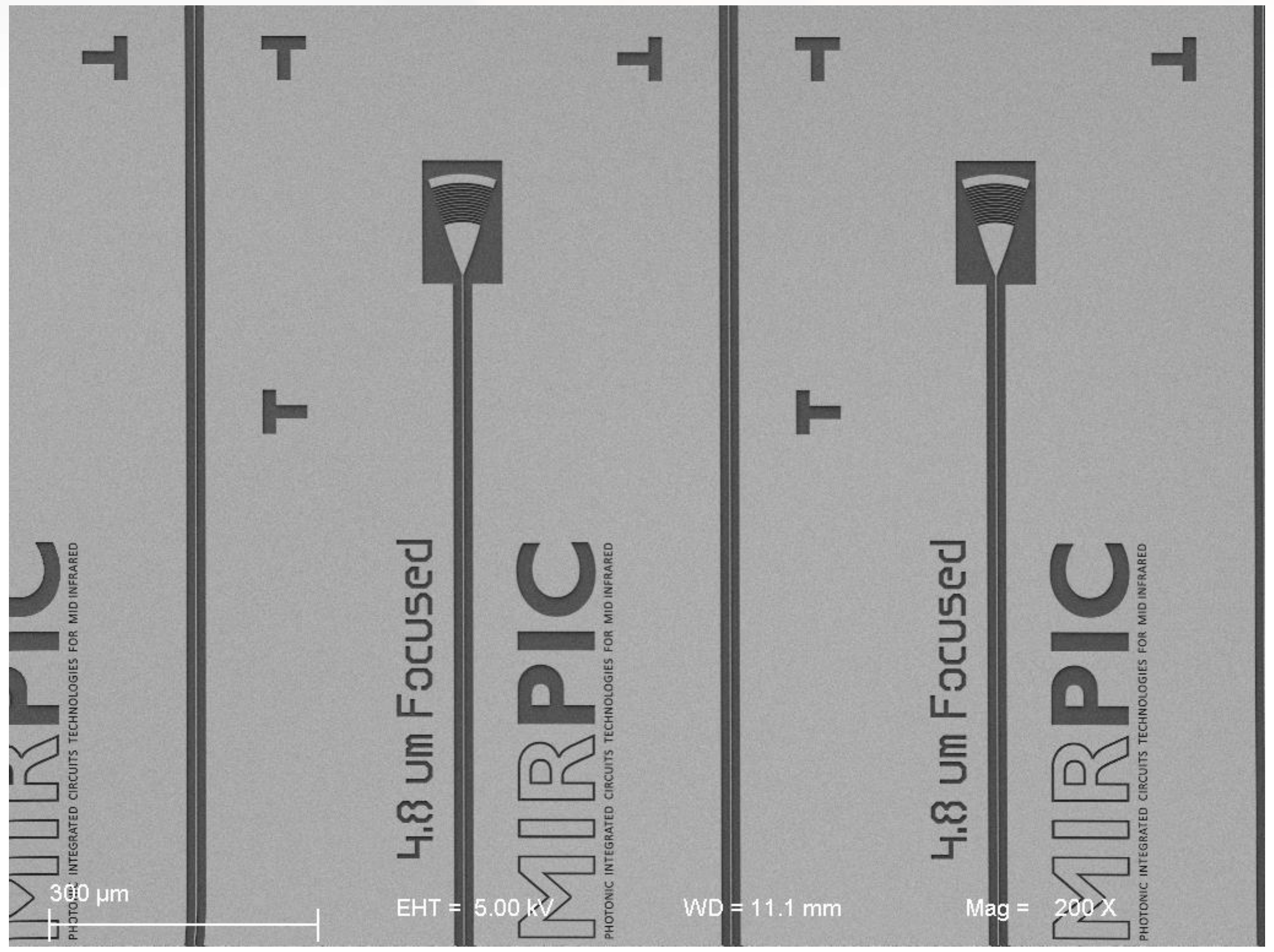
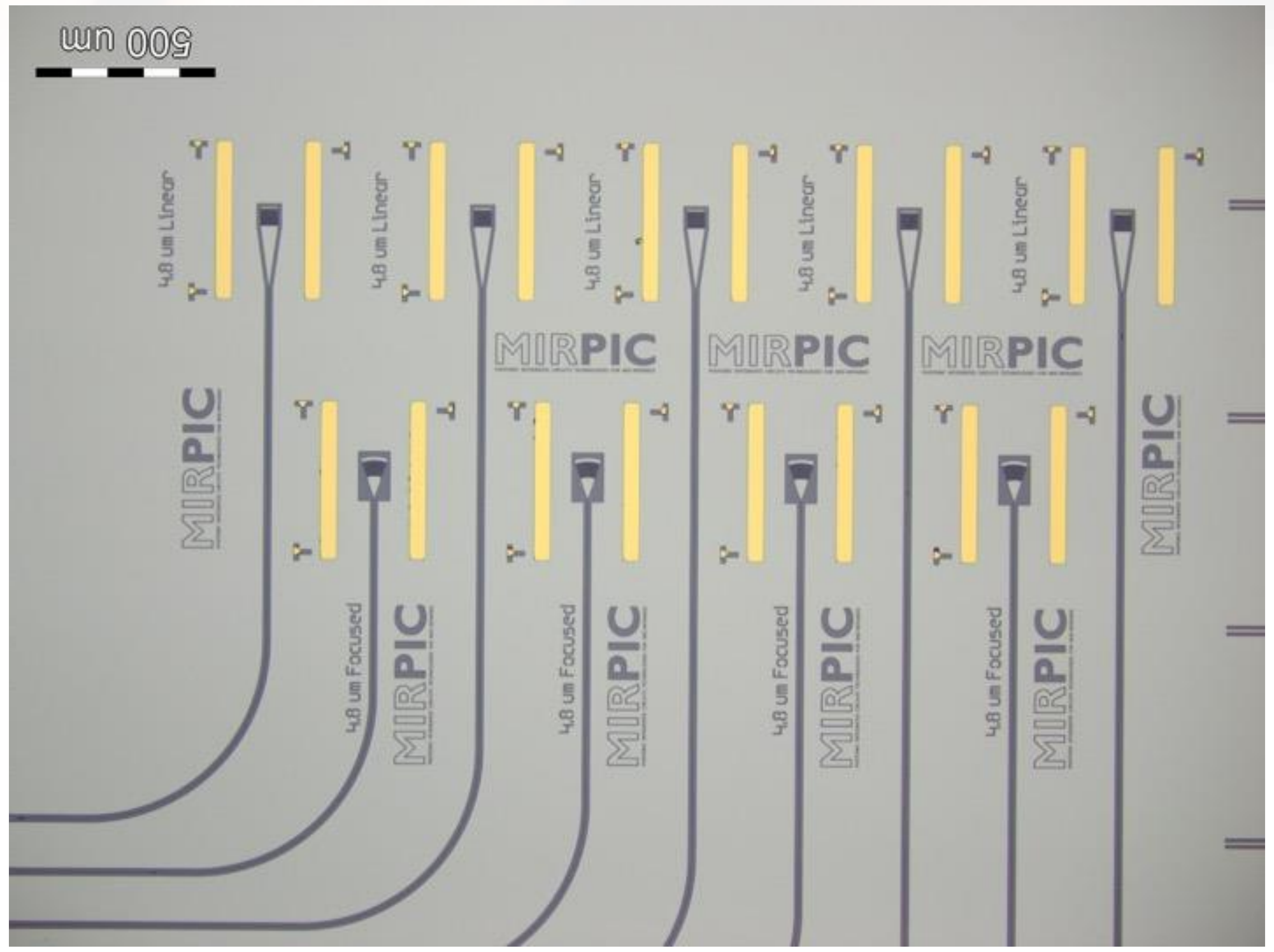
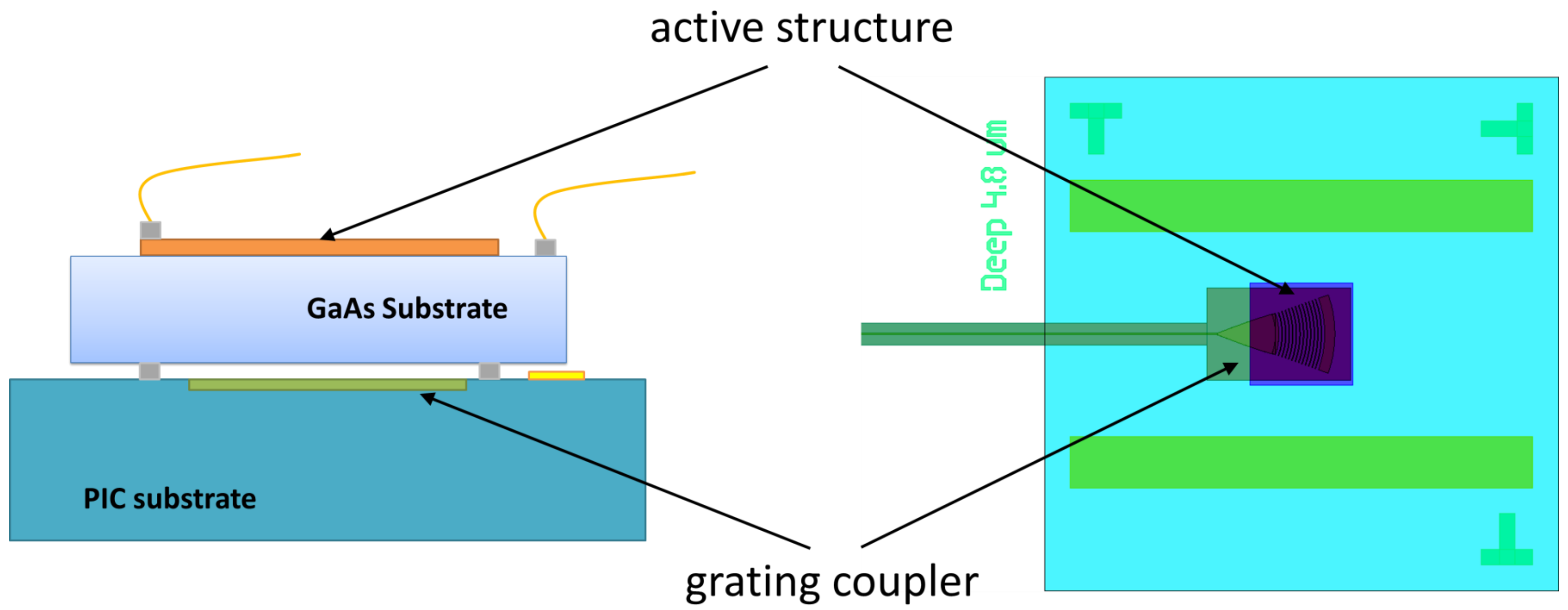
Integration with passive photonic circuits (Ge-on-Si)









First flip-chip integration tests in progress.

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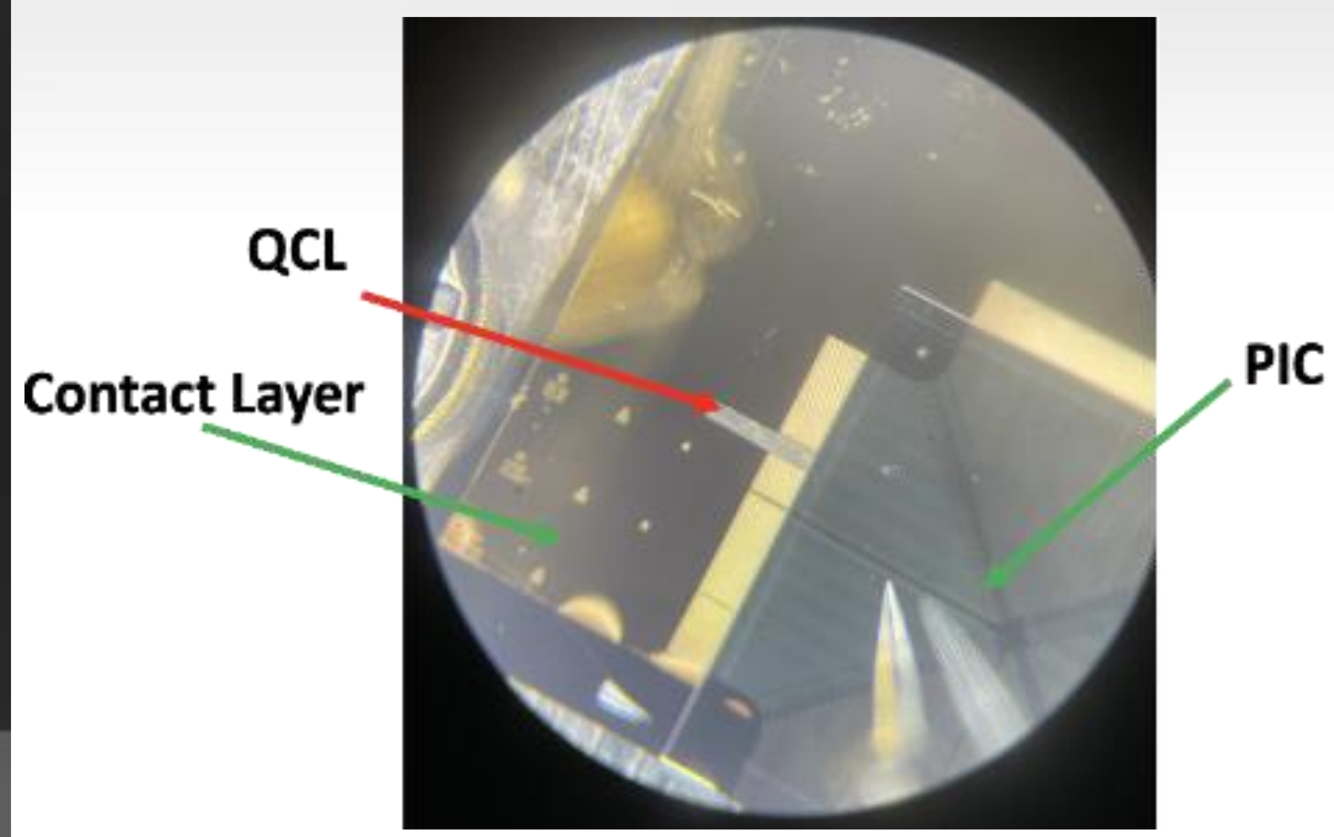
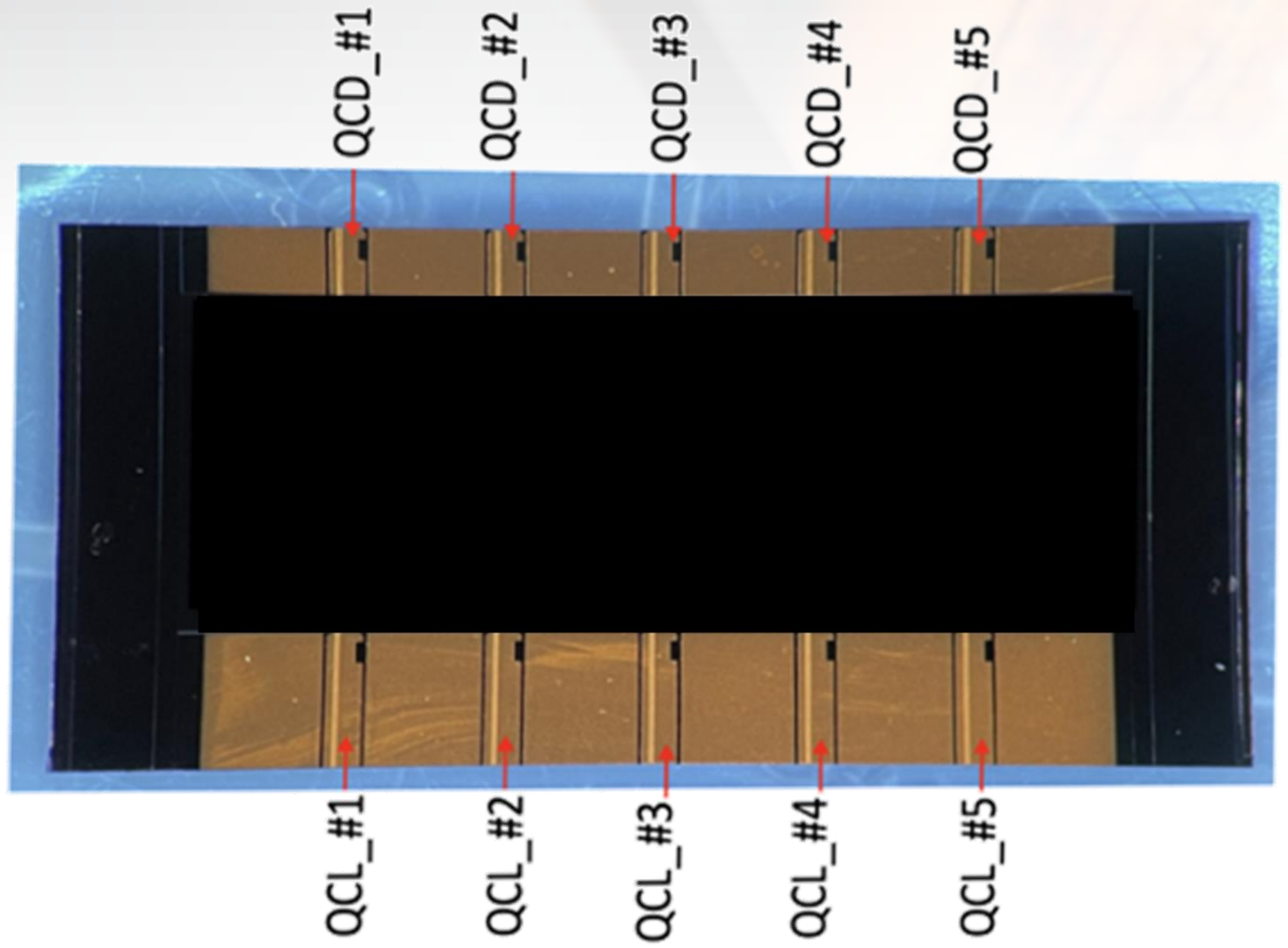
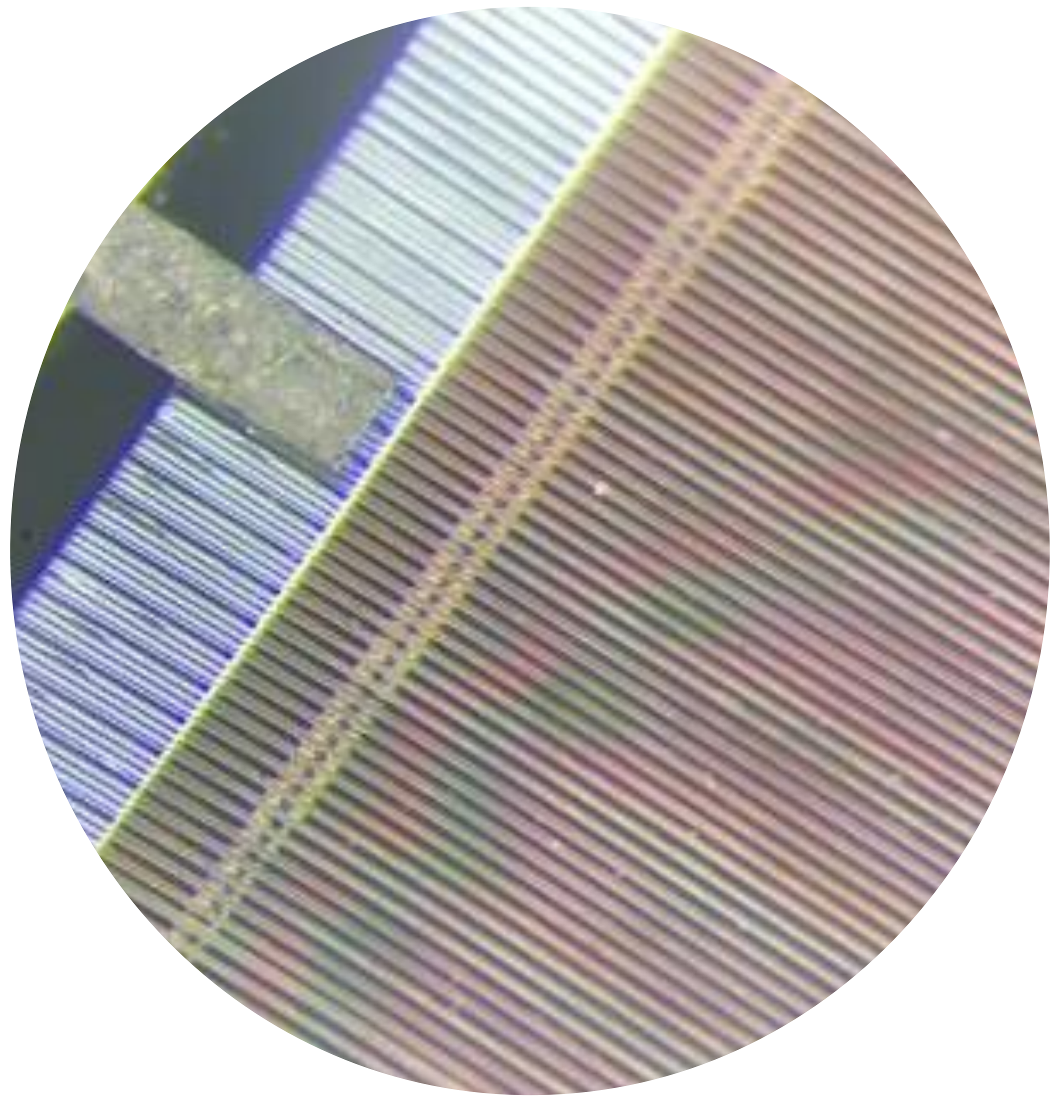
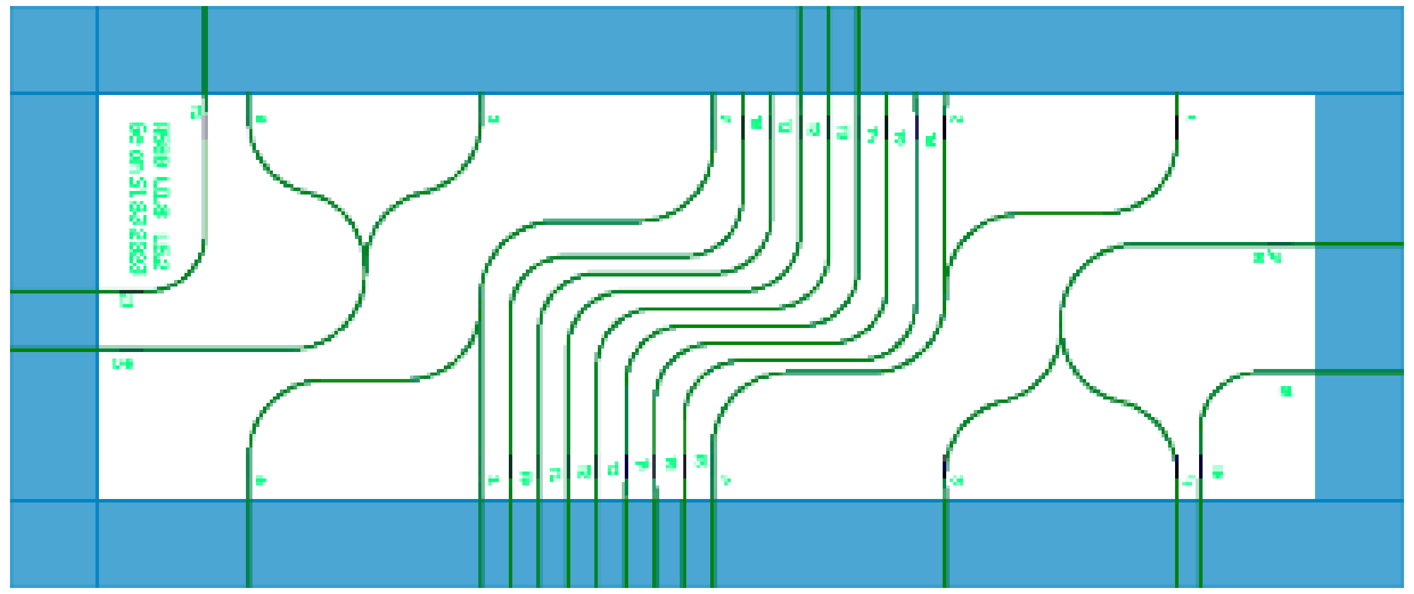
Integration and packaging

QCLs-waveguides integration experiments

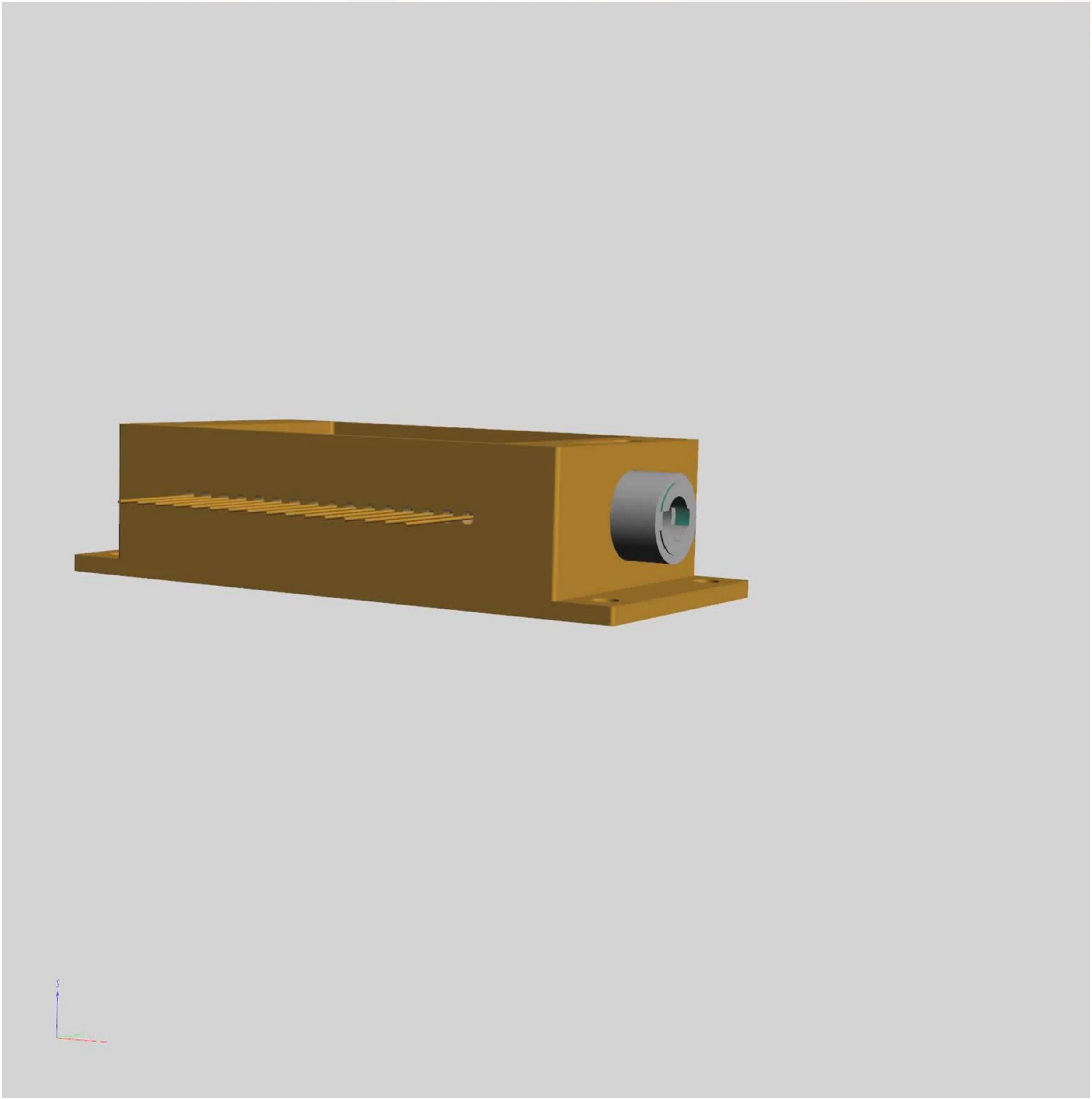




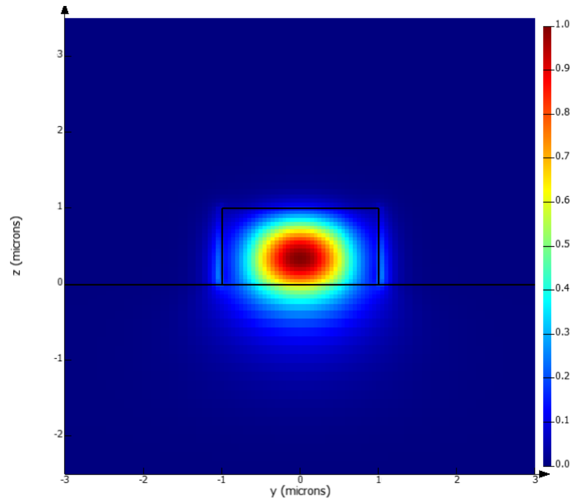
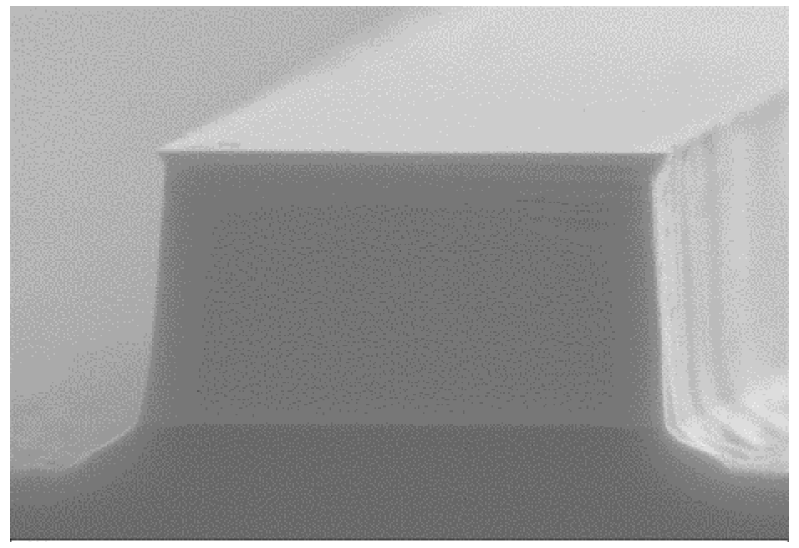
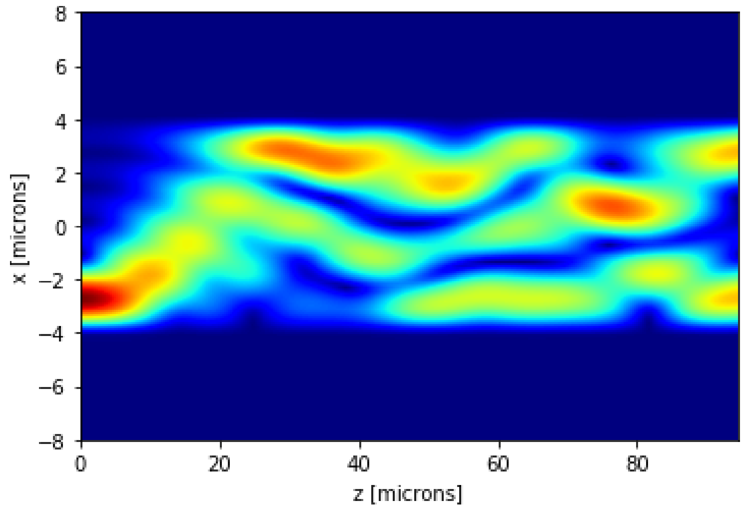
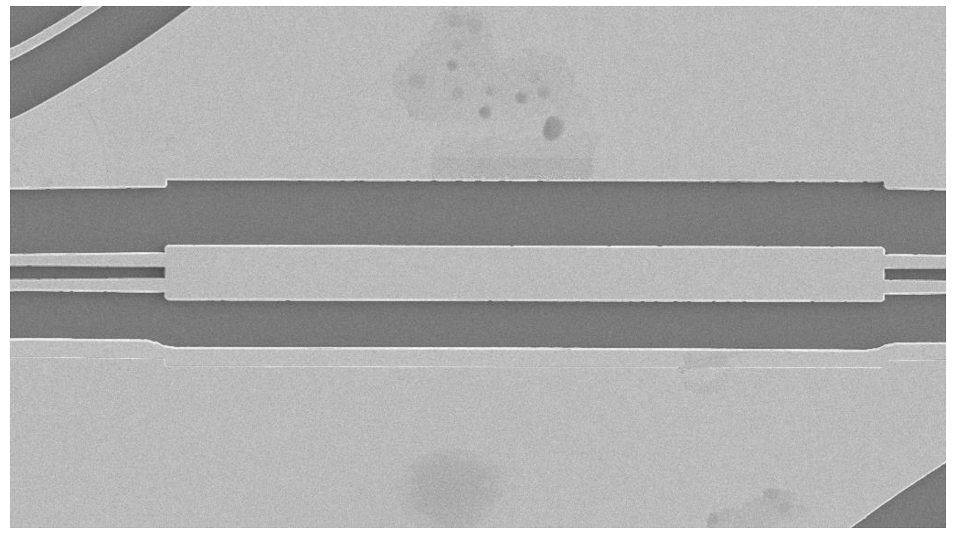
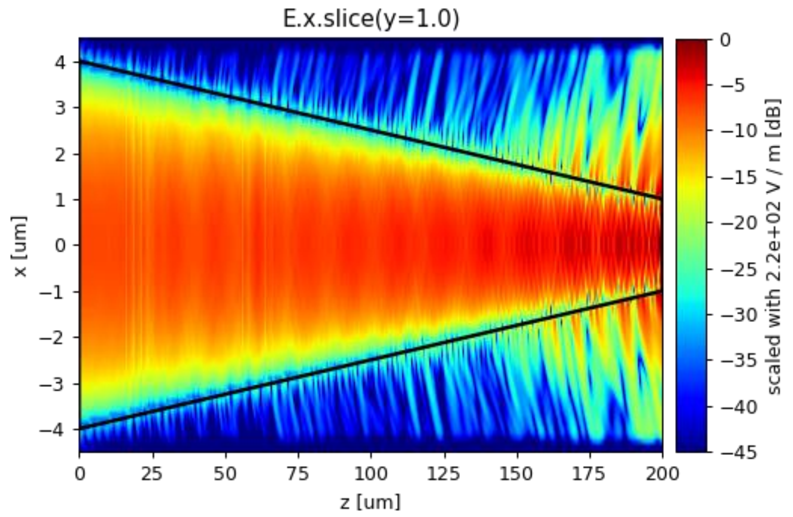
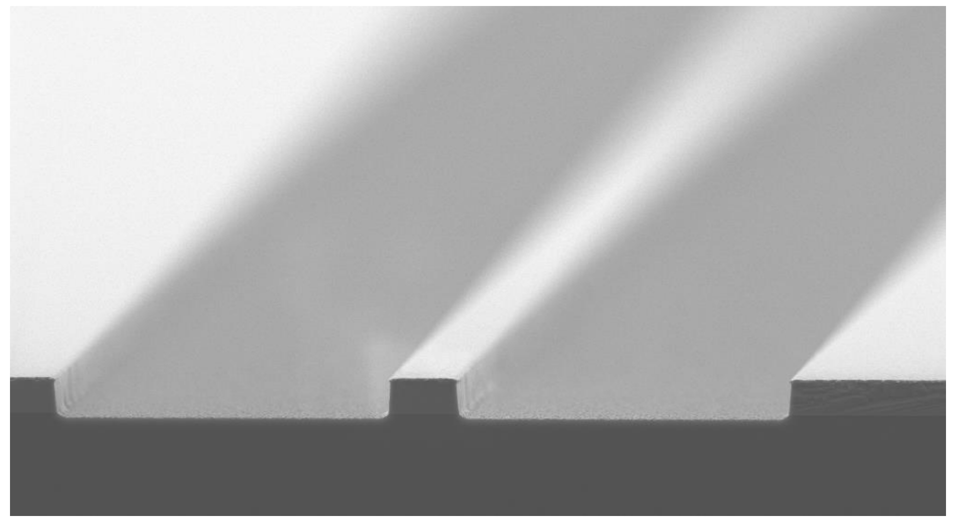




packaging concept



Components library

component	design	structure	parameters
Waveguide WG			▪ attenuation 2-3 dB/cm ▪ spectral range 3.0 – 5.5 μm ▪ minimum bending radius 500 μm ▪ minimum WG width 0.8 μm ▪ Ge layer thickness 1 μm and 2 μm
Multi-Mode Interference (MMI) coupler			▪ spectral range 3.0 – 5.5 μm ▪ excess loss below 0.8 dB ▪ 1×2, 2×2 and 1×4 configuration ▪ asymmetric splitting ratio available
Spot-Size Converter SSC			▪ spectral range 3.0 – 5.5 μm ▪ transmission 90% ▪ lateral taper (w_{out} = 8 μm)

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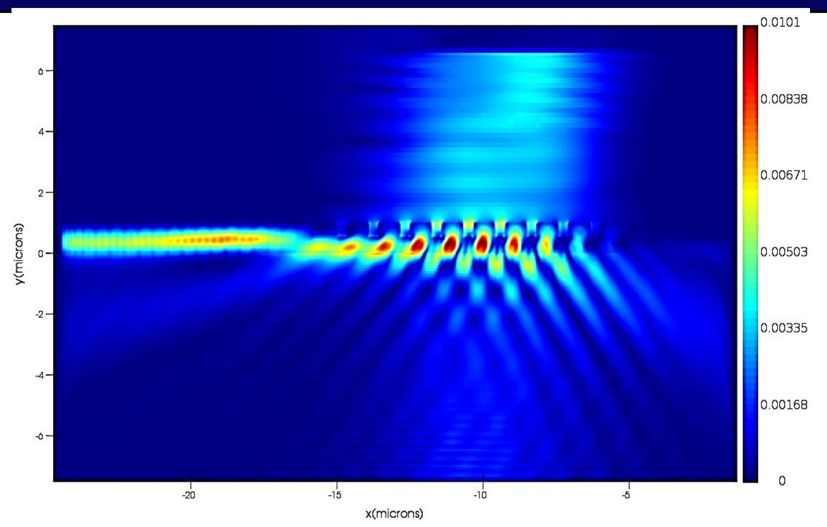
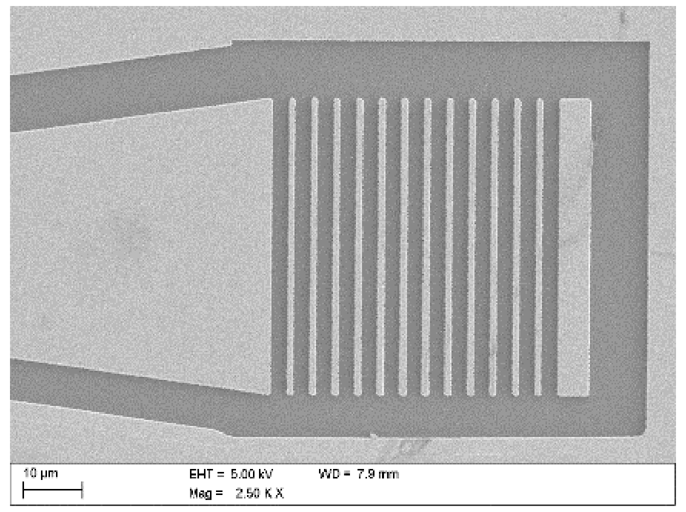
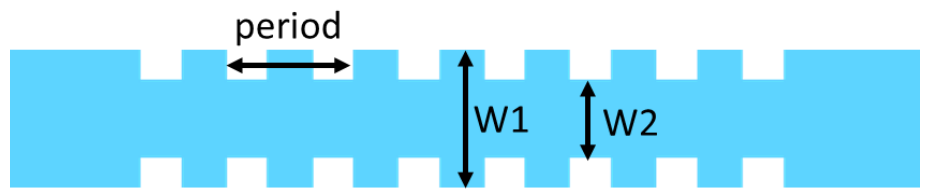
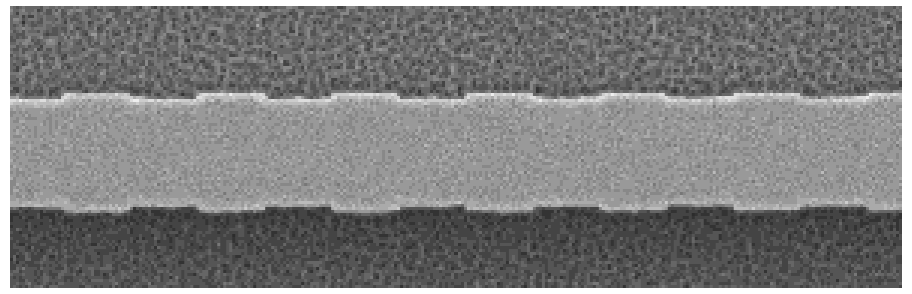
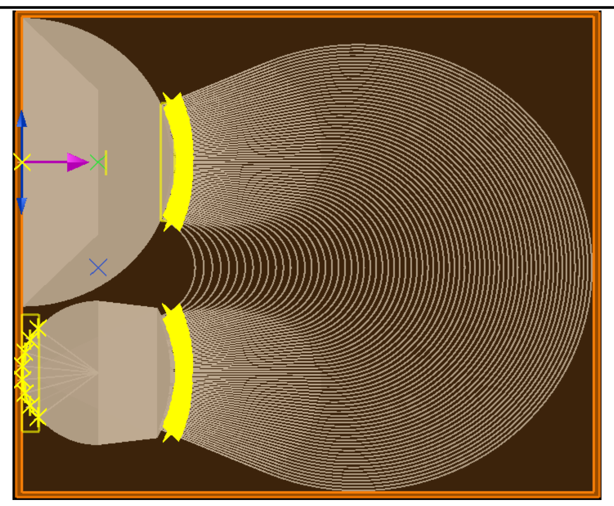
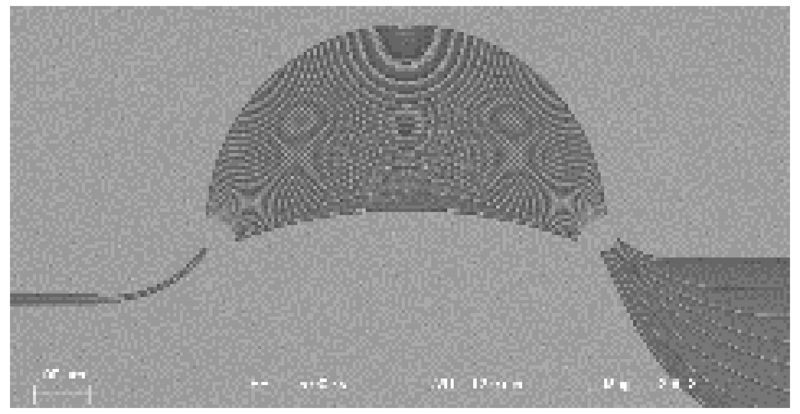
Components library

component	design	structure	parameters
Grating Coupler GC			▪ spectral range: 3.0 – 5.5 µm ▪ transmission above 15%
Distributed Bragg Reflector DBR			▪ Bragg wavelength: 3.0 – 5.5 µm ▪ reflectivity above 80% ▪ tailored spectral width ▪ side lobe suppression above 10 dB
Arrayed Waveguide Grating AWG			▪ spectral range: 3.0 – 5.5 µm ▪ insertion loss below 4 dB ▪ arbitrary λ_c, $\Delta\lambda$ and FSR

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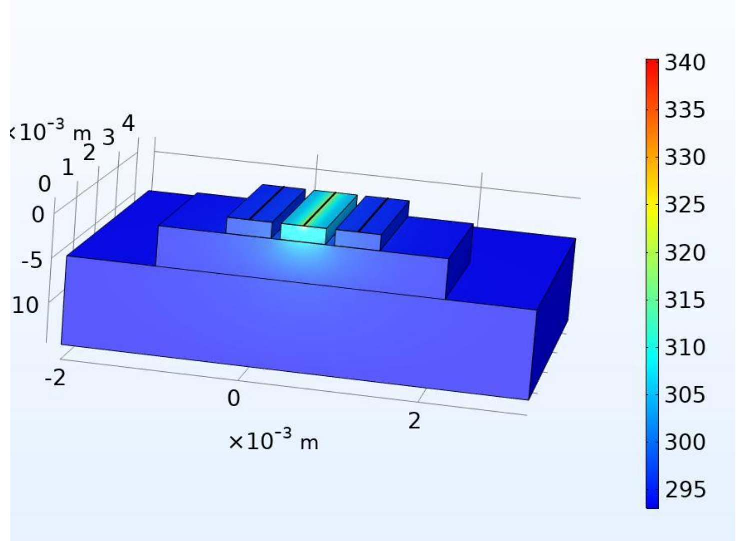
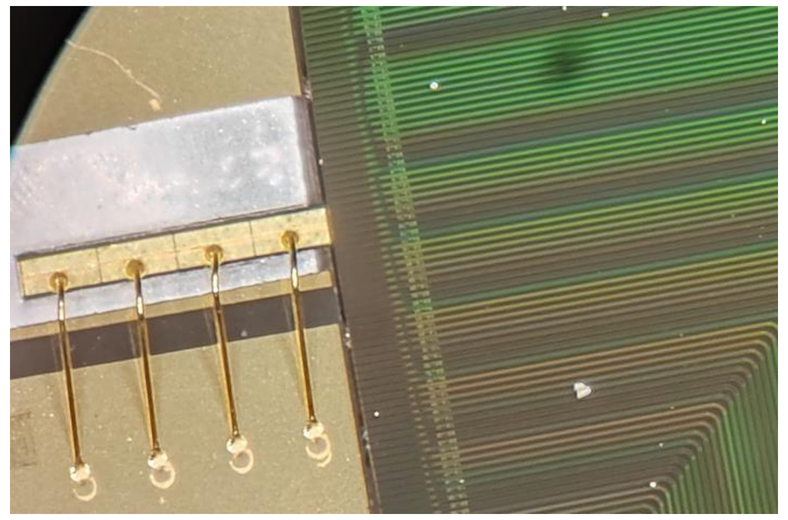
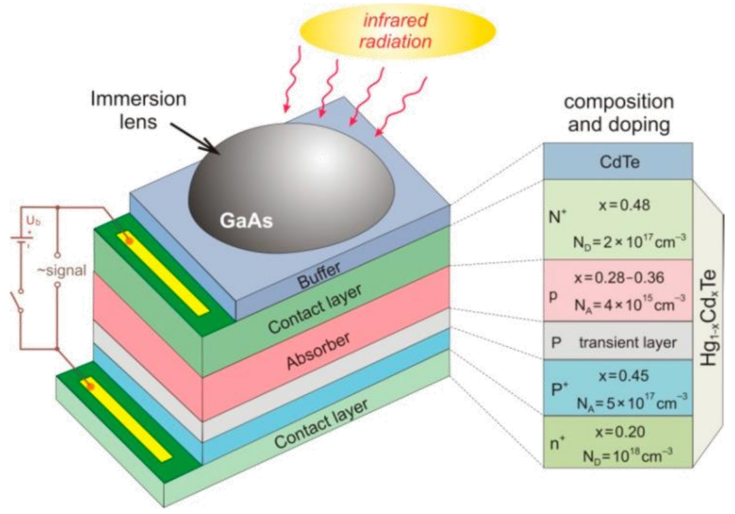
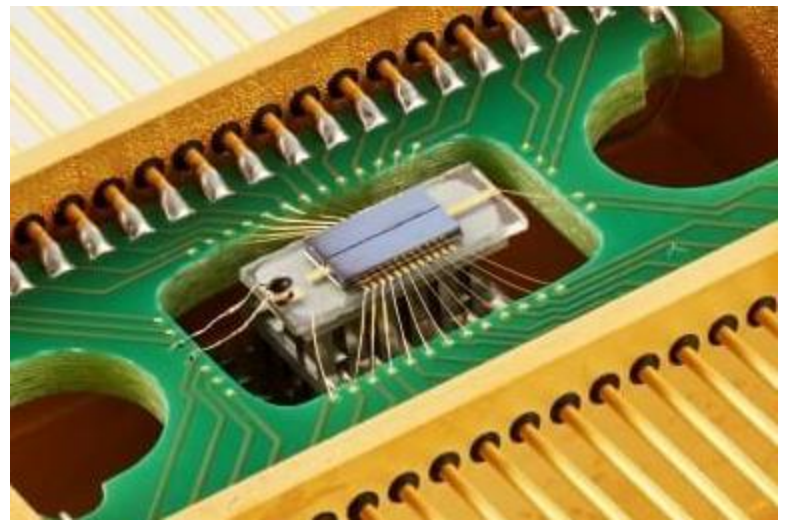
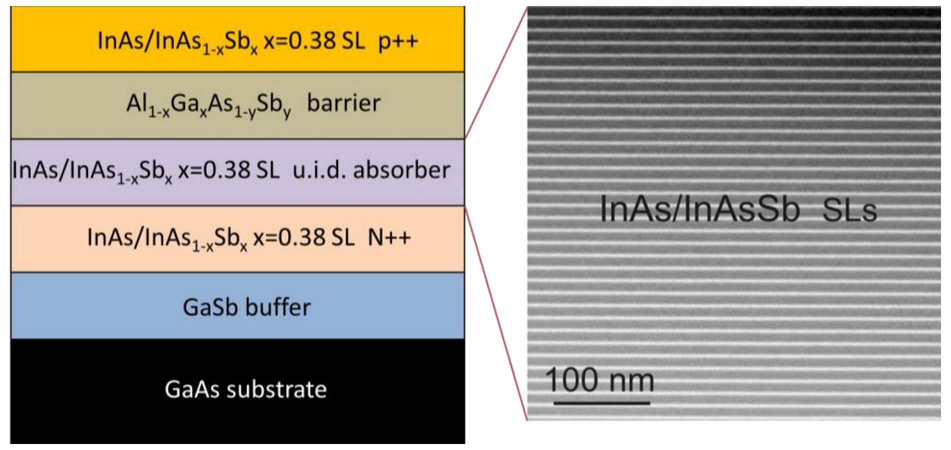
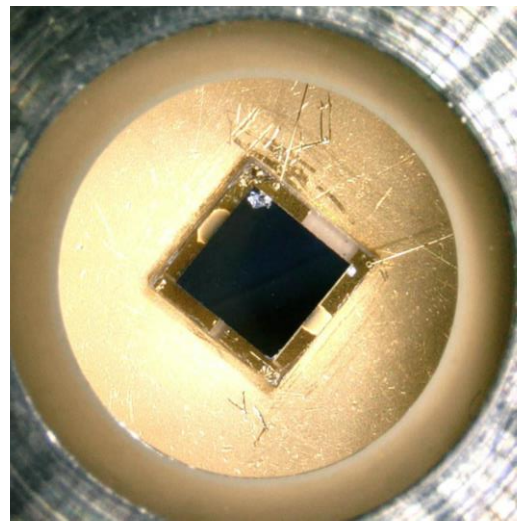
Components library

component	design	structure	parameters
QCL laser			▪ spectral range 4.4 – 5.2 µm ▪ pulse power 500 mW ▪ pulse duration 0.2 – 1.0 µs ▪ I_{th} < 3.0 A ▪ U < 18.0 V
MCT detector			▪ spectral range 2 – 14 µm ▪ detectivity (room temperature) $5*10^{10}$ - $5*10^{7}$ $cmHz^{1/2}W^{-1}$ ▪ bandwidth up to 2 GHz
SL antimonide detector			▪ spectral range 1.7 – 13 µm ▪ detectivity (room temperature) $5·10^{10}$ – $7·10^{7}$ $cmHz^{1/2}W^{-1}$ ▪ bandwidth up to 5 GHz ▪ ROHS compliant

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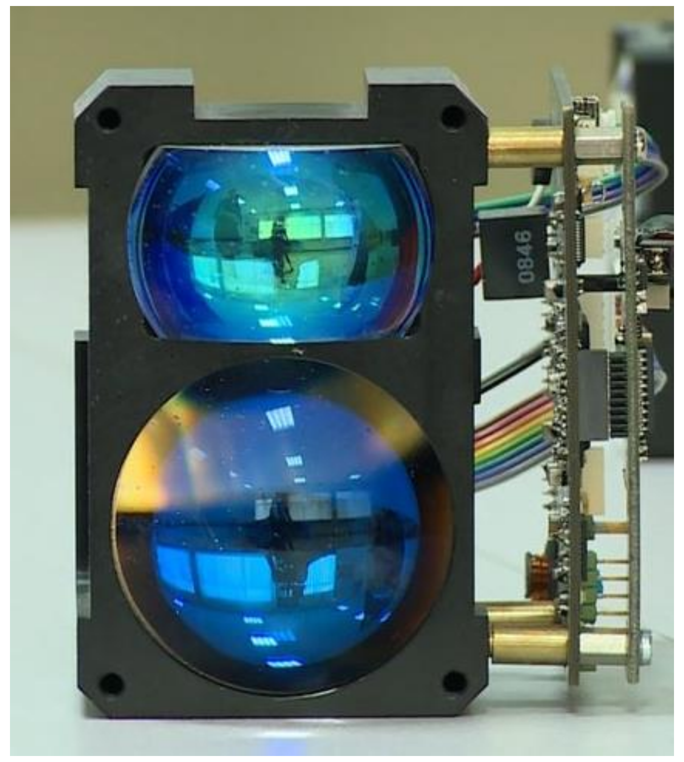
Next steps

- QCLs and detectors integrated with waveguides (in progress)
- First MIRPICs packaged (end of 2024)
- Line-up of technology demonstrators (on the roadmap)

FSOC transmitter



Dec. 2024

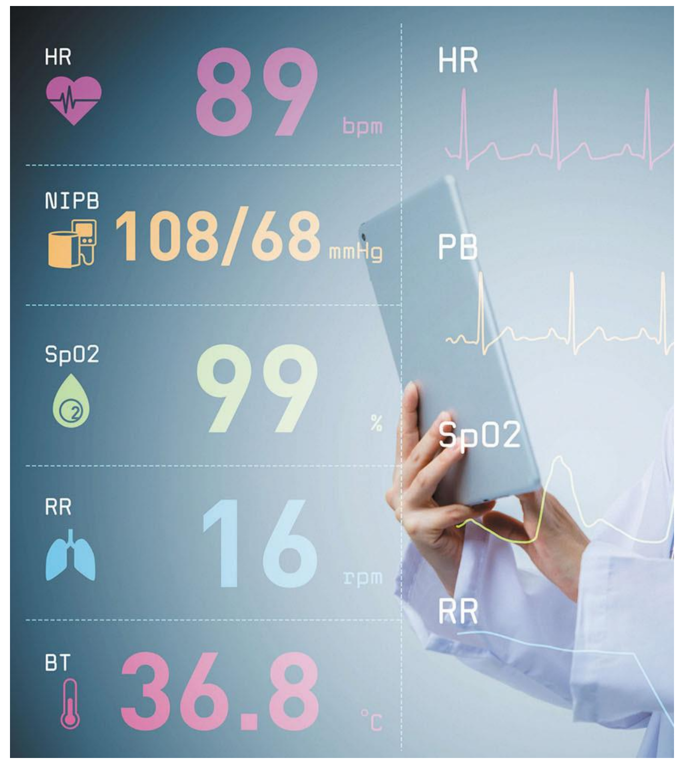
Gas analyzer

Dec. 2025

Driver condition monitoring

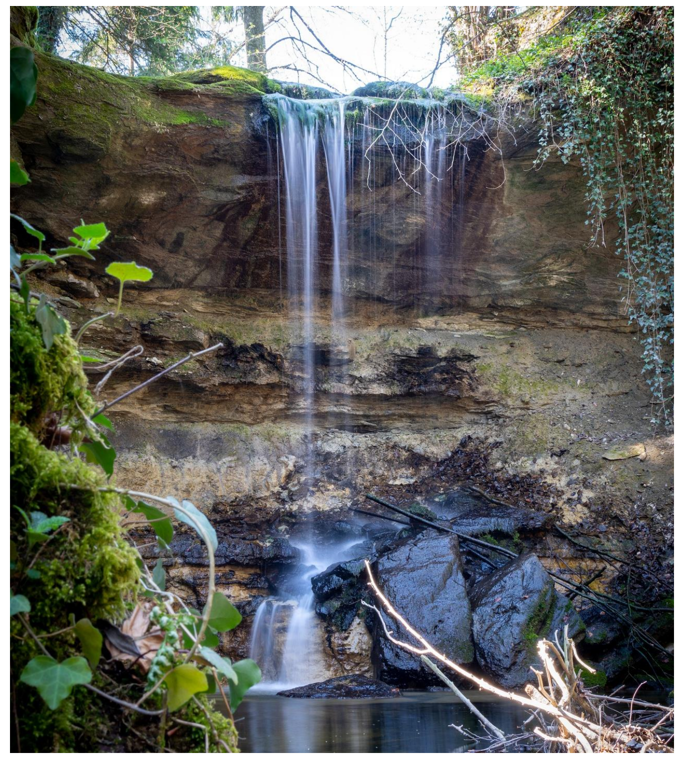
June 2026

Breath analyzer



June 2026

Water quality monitoring



March 2027

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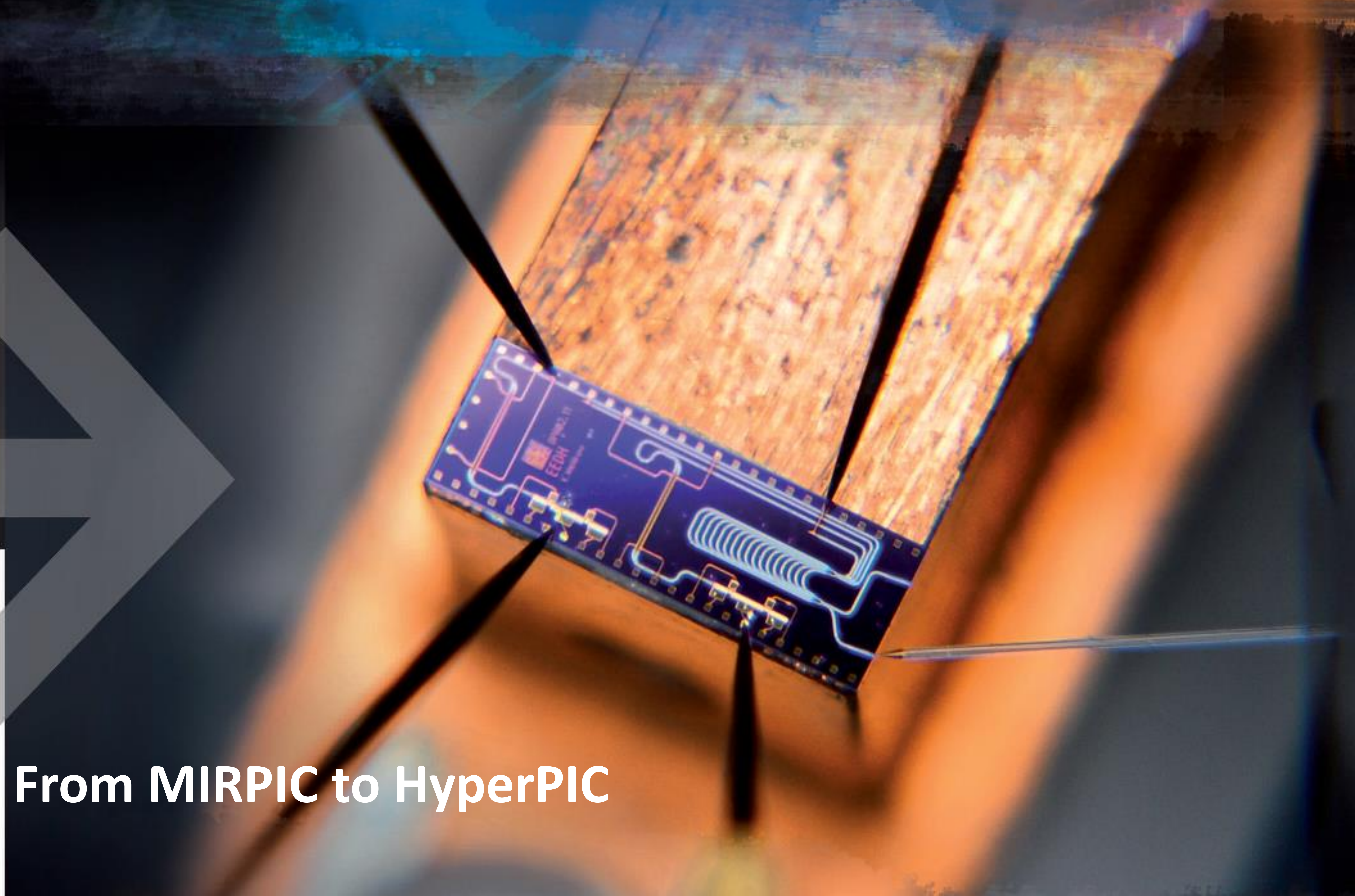

From MIRPIC to HyperPIC

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IPCEI – Important Projects of Common European Interest

The context

https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

Growing global demand for semiconductors

Digital sovereignty – EC proposes Chips Act to confront semiconductor shortages and strengthen Europe's technological leadership.

European Commission

EUROPEAN CHIPS ACT

February 2022
#EUChipsAct #DigitalEU

Our aim is to jointly create a state-of-the-art European chip ecosystem, including production. We need to link together our world-class research, design and testing capacities. We need to coordinate EU and national investment along the value chain. This is not just a matter of our competitiveness. This is also a matter of tech sovereignty.

Ursula von der Leyen
President of the European Commission, 2021 State of the Union address

Semiconductor chips are the essential building blocks of digital products we use constantly ranging from smartphones and computers, to appliances in our homes, lifesaving medical equipment, communication, energy, industrial automation etc. Chips are everywhere.

In 2020, more than **1 trillion microchips** were manufactured around the world, about **130 chips for every person on earth**

World shortage since 2020

Higher prices | Lengthier delivery for consumer electronics and life-saving equipment | Car

Europe is strong in some specific areas

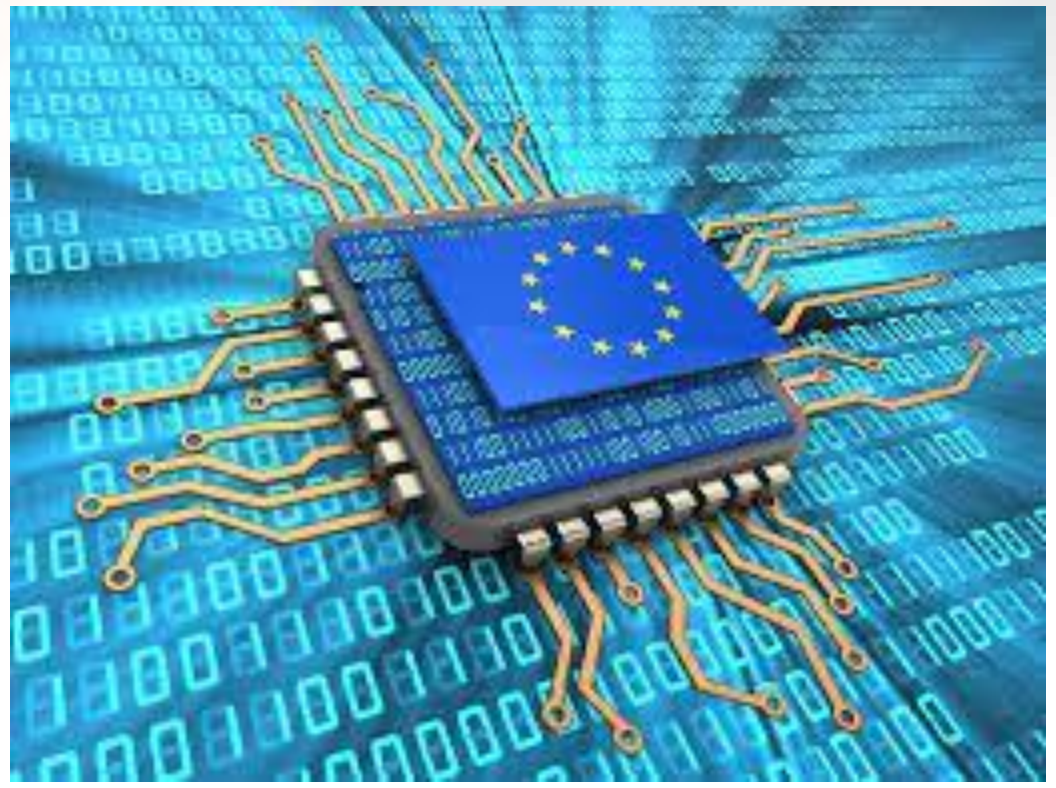
Semiconductor research: World leading techniques behind most advanced chips | Chip manufacturing equipment: central equipment for all advanced chips | Silicon wafer: mirror-like material es manufacturing semico

However, **the EU has only roughly 10% of global market share** and is heavily

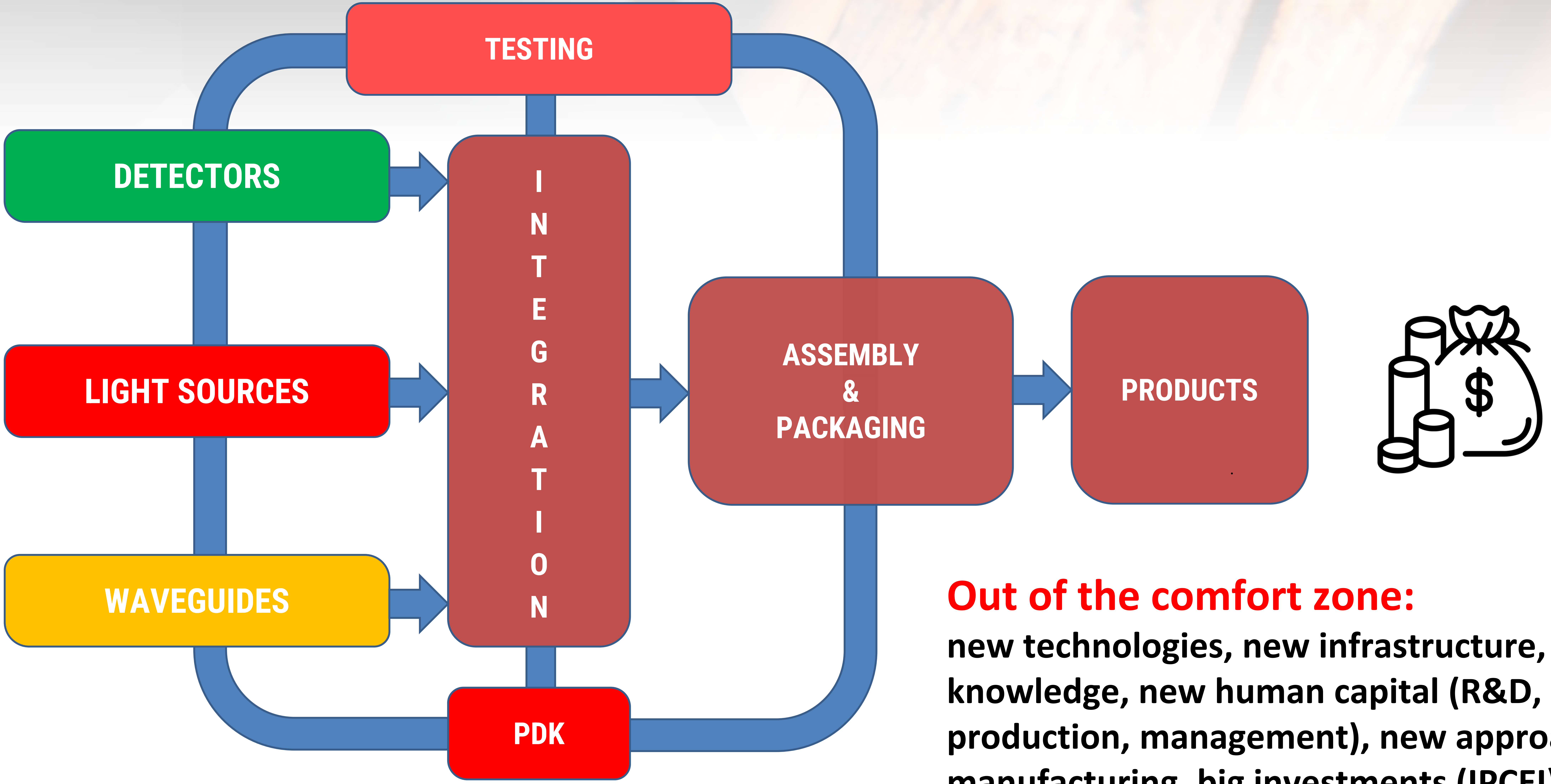
The EU aims to play a leading role in the design and manufacturing of the next generation of microchips, down to 2 nanometers nodes and below. A nanometer is how much a fingernail grows per second.

Current state of art in chips: engraving at 5 nanometres

2022: 3 nanometres semiconductor goes into production .... 2 nanometres and below are expected in **2024**



HyperPIC proposal within IPCEI mechanism



Out of the comfort zone:

new technologies, new infrastructure, new knowledge, new human capital (R&D, production, management), new approach to manufacturing, big investments (IPCEI)

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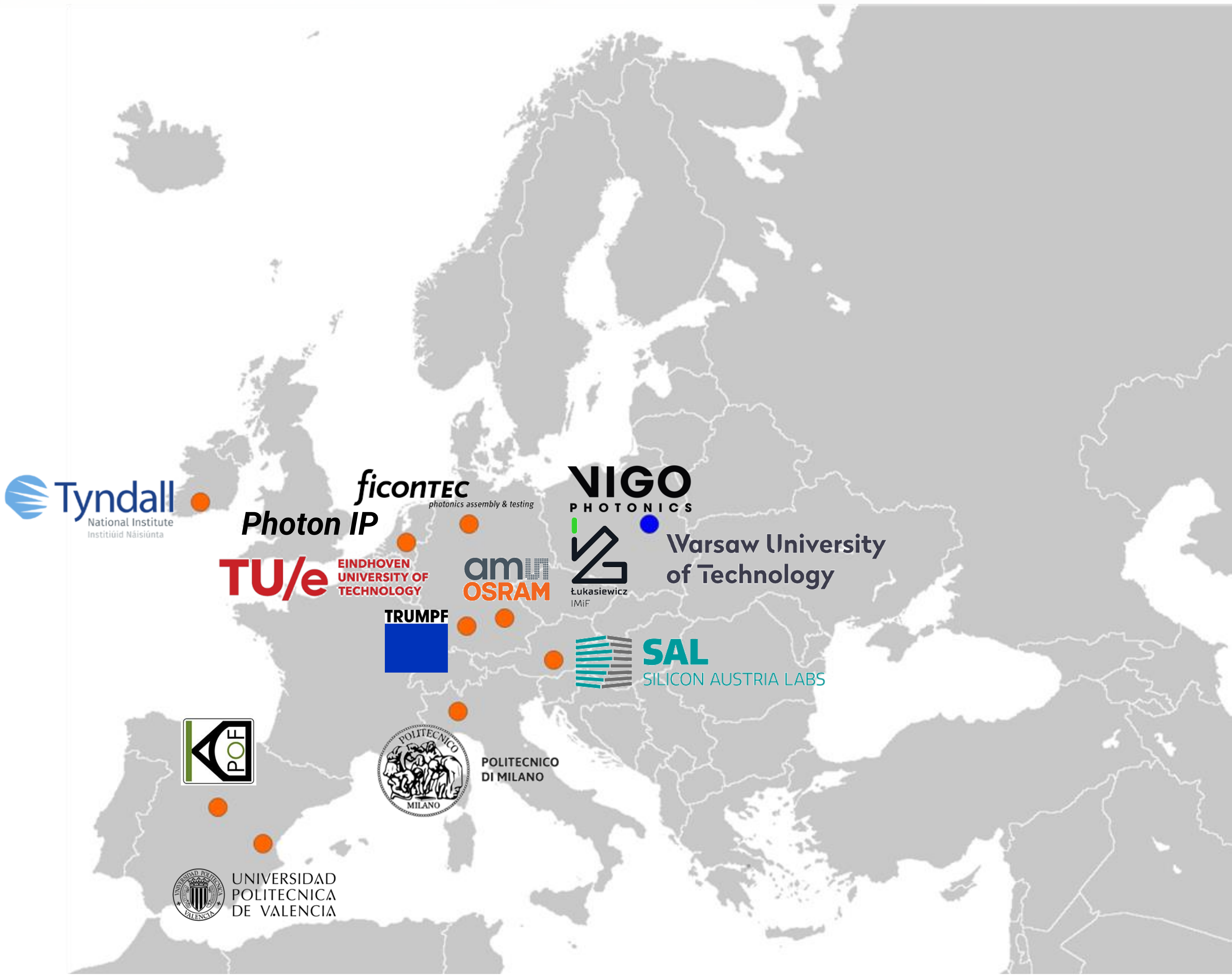
HyperPIC proposal within IPCEI mechanism

HyperPIC R&D partners

1. VIGO Photonics
2. Warsaw University of Technology
3. Institute of Microelectronics and Photonics SBŁ
4. Universitat Politecnica de Valencia
5. Eindhoven University of Technology
6. Politecnico di Milano
7. Tyndall National Institute
8. Silicon Austria Labs
9. Photon IP
10. Ficontec
11. KDPOF
12. TRUMPF Photonic Components
13. ams Osram



HyperPIC proposal within IPCEI mechanism

European Commission

English EN

Search

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Available languages: English

Press release | 8 June 2023 | Brussels

State aid: Commission approves up to €8.1 billion of public support by fourteen Member States for an Important Project of Common European Interest in microelectronics and communication technologies

The first workstream "Sense" will focus on **developing novel sensors** able to collect relevant analogue signals from our environment and translate them into digital data. Vigo, a Polish SME, will develop sensors in highly compact integrated circuits, replacing the current complex and large systems.

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innovation and the first industrial deployment of microelectronics and communication technologies across the value chain.

The project, called **"IPCEI ME/CT"**, was jointly prepared and notified by fourteen Member States: Austria, Czechia, Finland, France, Germany, Greece, Ireland, Italy, Malta, the Netherlands, Poland, Romania, Slovakia and Spain.

Total budget: ca. 253.4 mln EUR

Public aid: ca. 102.9 mln EUR

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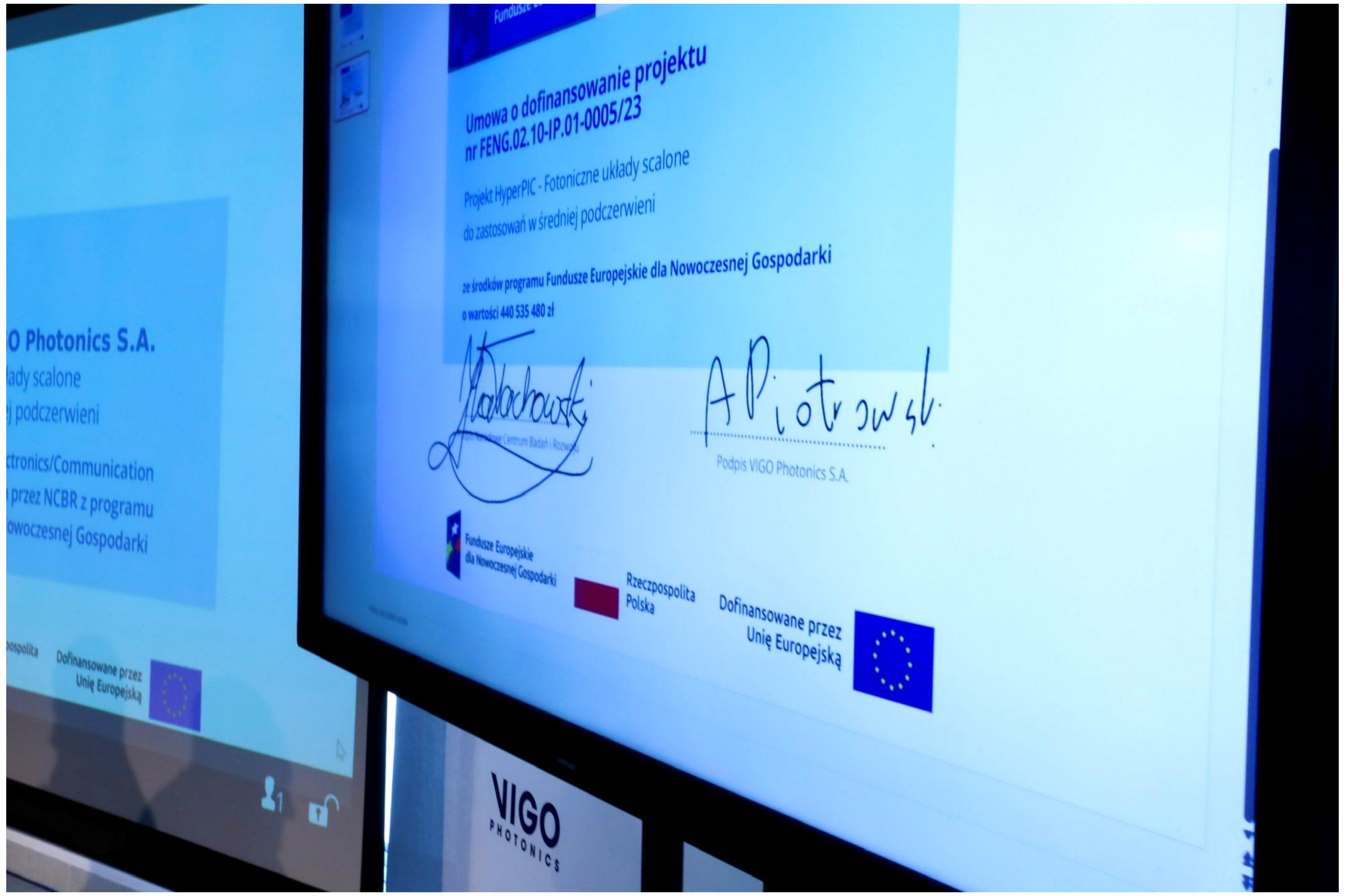
IPCEI – Important Projects of Common European Interest

Contract between VIGO and NCBR signed on 14th May 2024

HyperPIC – Fotoniczne układy scalone do zastosowań w średniej podczerwieni

HyperPIC – Photonic integrated circuits for applications in mid-infrared



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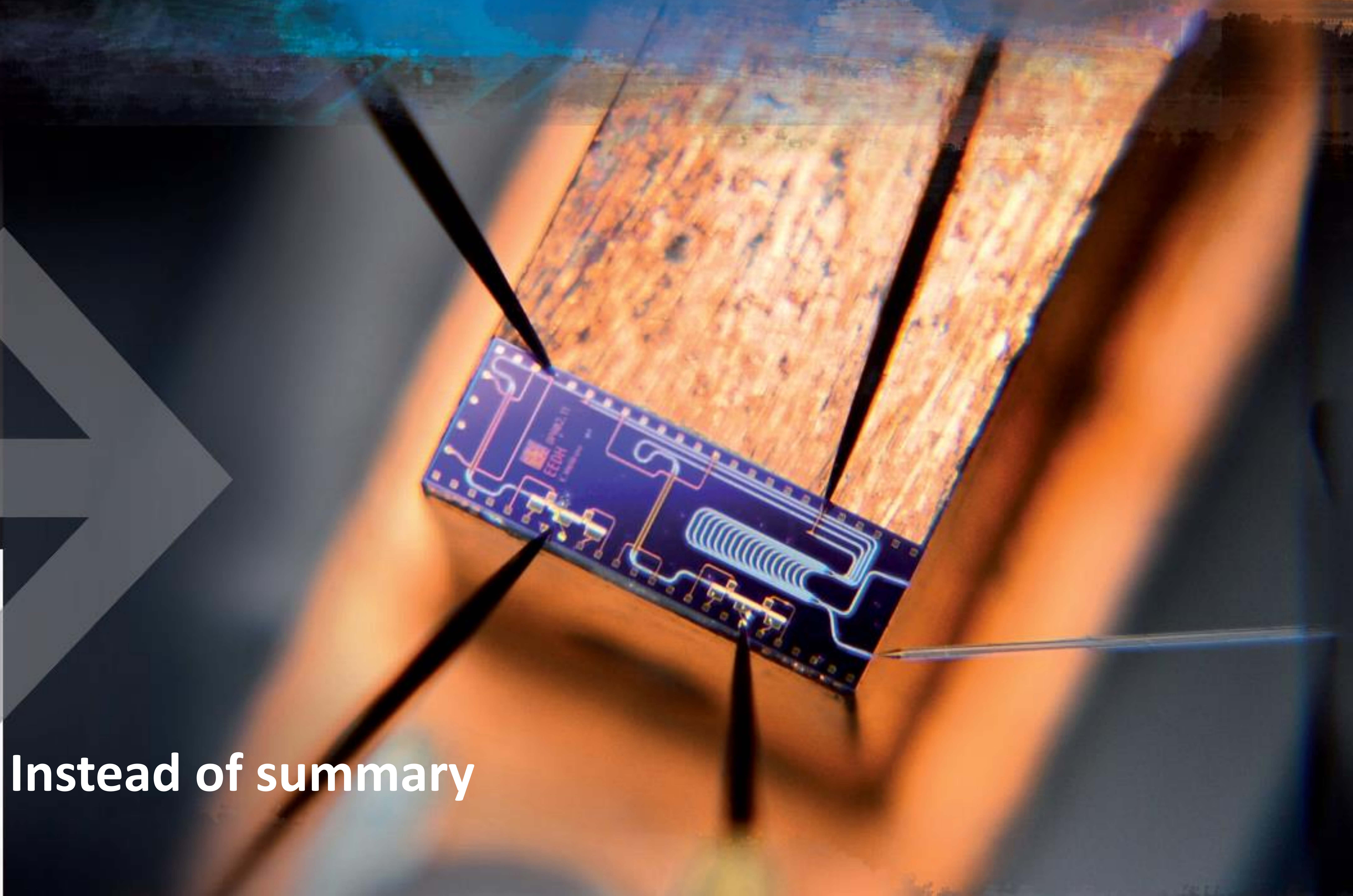

Instead of summary

Every journey begins with a first step...

Every journey begins with a first step…

HyperPIC is a very long journey,
big challenge, a unique opportunity, and a big adventure!

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