ECOPIC – **ECO**system for **P**hotonic **I**ntegrated **C**ircuits

ITNT 2022, Samara, May 23, 2022

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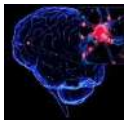
Skoltech
Skolkovo Institute of Science and Technology

Skoltech – structures and goals

MOLECULAR AND CELLULAR BIOLOGY

NEUROBIOLOGY AND BRAIN REHABILITATION



PETROLEUM SCIENCE AND ENGINEERING

PHOTONIC SCIENCE AND ENGINEERING

Skoltech

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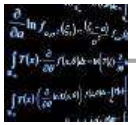
MATERIAL TECHNOLOGY

ENERGY SCIENCE AND TECHNOLOGY

DIGITAL ENGINEERING

ENGINEERING PHYSICS

ADVANCED STUDIES



ARTIFICIAL INTELLIGENCE TECHNOLOGY

Skoltech

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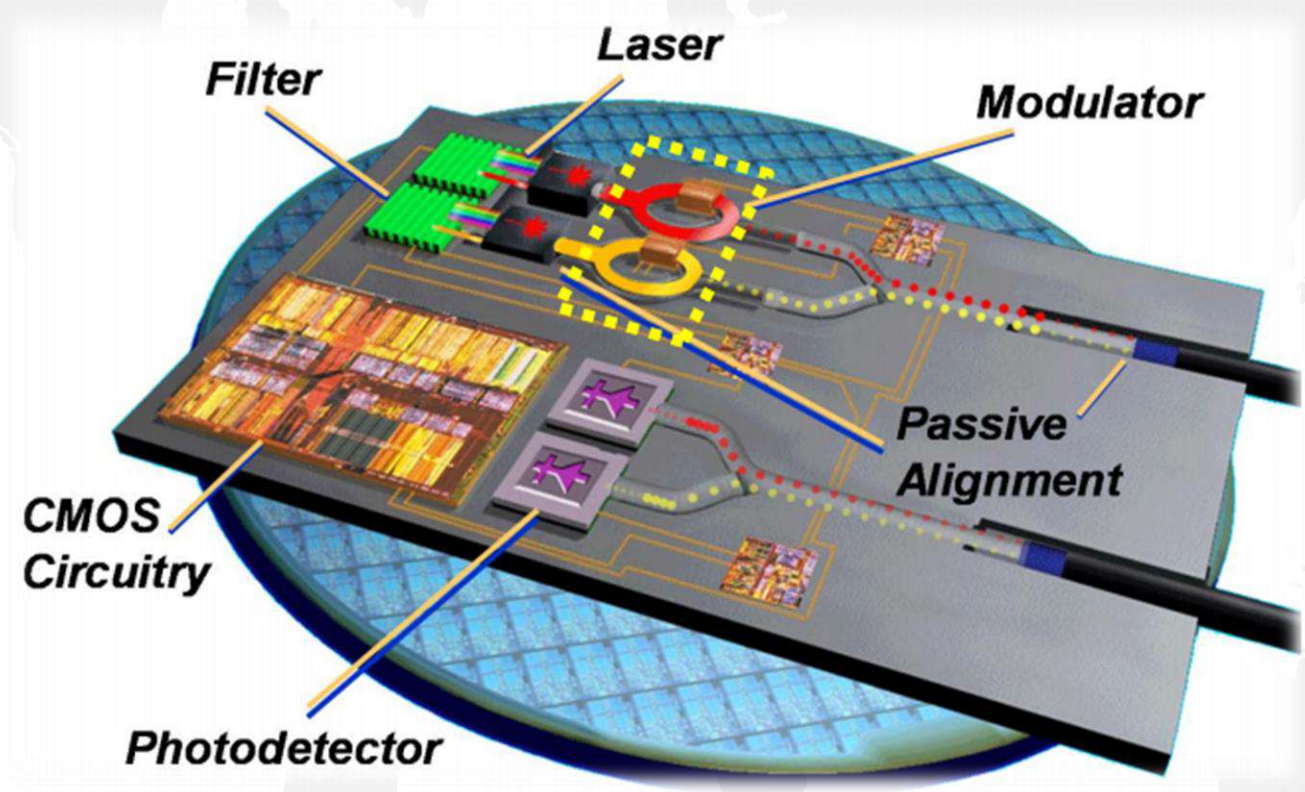
ECOPIC – **ECO**system of **P**hotonic **I**ntegrated **C**ircuits



Electronics 20th → Photonics 21st

Future of photonic – nomenclature of PICs

Microelectronics

Discrete electronics

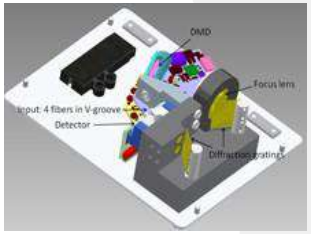
Qualitative transition

Modern microelectronics based on integrated circuits - ICs

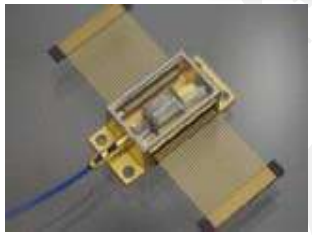
1950 1960 1970 1980 1990 2000 2010 **2019** 2010

Photonics

Qualitative transition



Discrete photonics



Semicondustor based PIC

Industrial standards for design and fabrication. Concept of foundries&PDK, MPW etc.

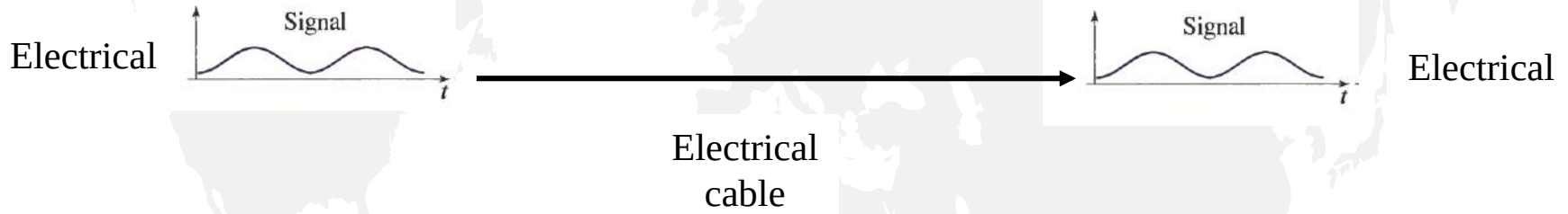
Applications / Markets vs. Technologies

Low Frequency High Frequency Terahertz

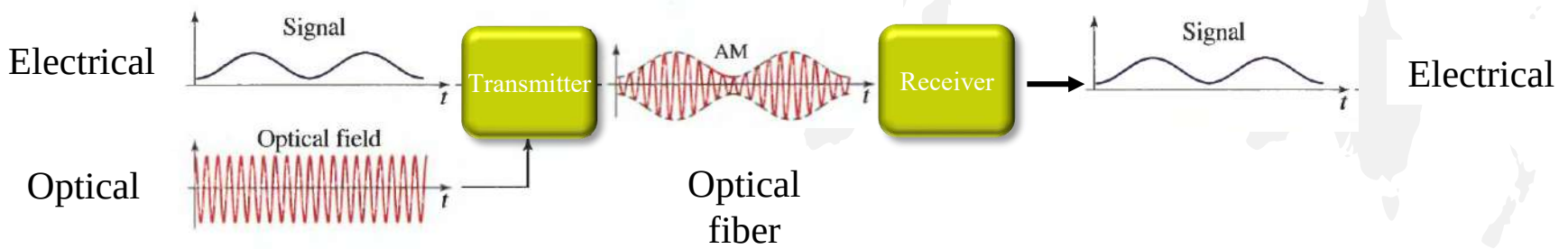
N	Markets/Technologies	PIC - LF	PIC - HF	PIC-THz	PIC-Quantum	Lasers on chip
1	**Optical communication**, including free space, 5/6G, QKD/QRNG, neural networks	X	X	X	X	X
2	**Radiophotonics** (radar&lidar, ADC, etc.)	X	X	X	X	X
3	**Structural Health Monitoring**, including neural networks	X	X	X		X
4	**Atomic Clock /Networking**	X	X		X	X
5	**Optical computing** (quantum, classic)	X	X	X		X
6	**Optical Simulator**, including neural networks	X	X		X	X
7	**Bio-medical photonics**	X	X	X	X	X
8	**Agricultural photonics**	X	X	X		X

Photonics and optical communication

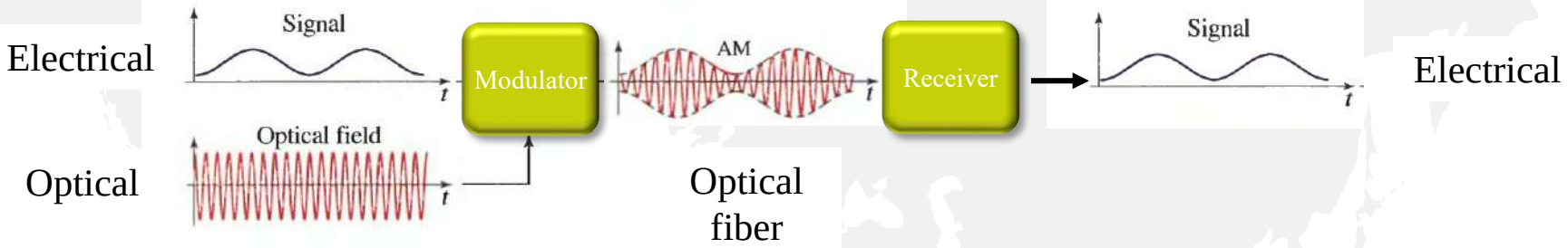
Electric cables – low frequencies, short distances for high frequencies

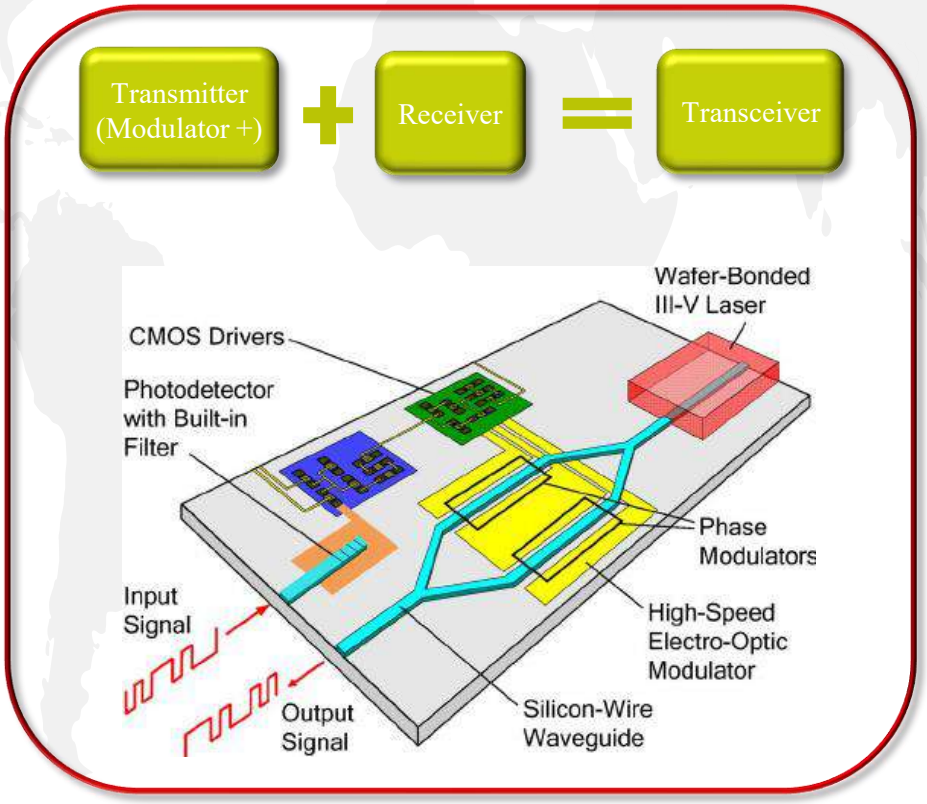


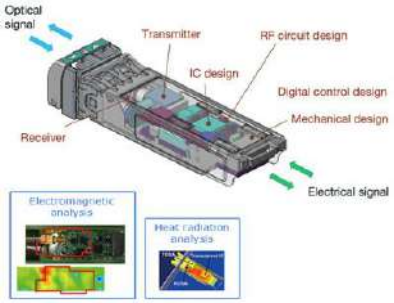
Optical fibers – high frequencies, unlimited distances



PIC and optical communication

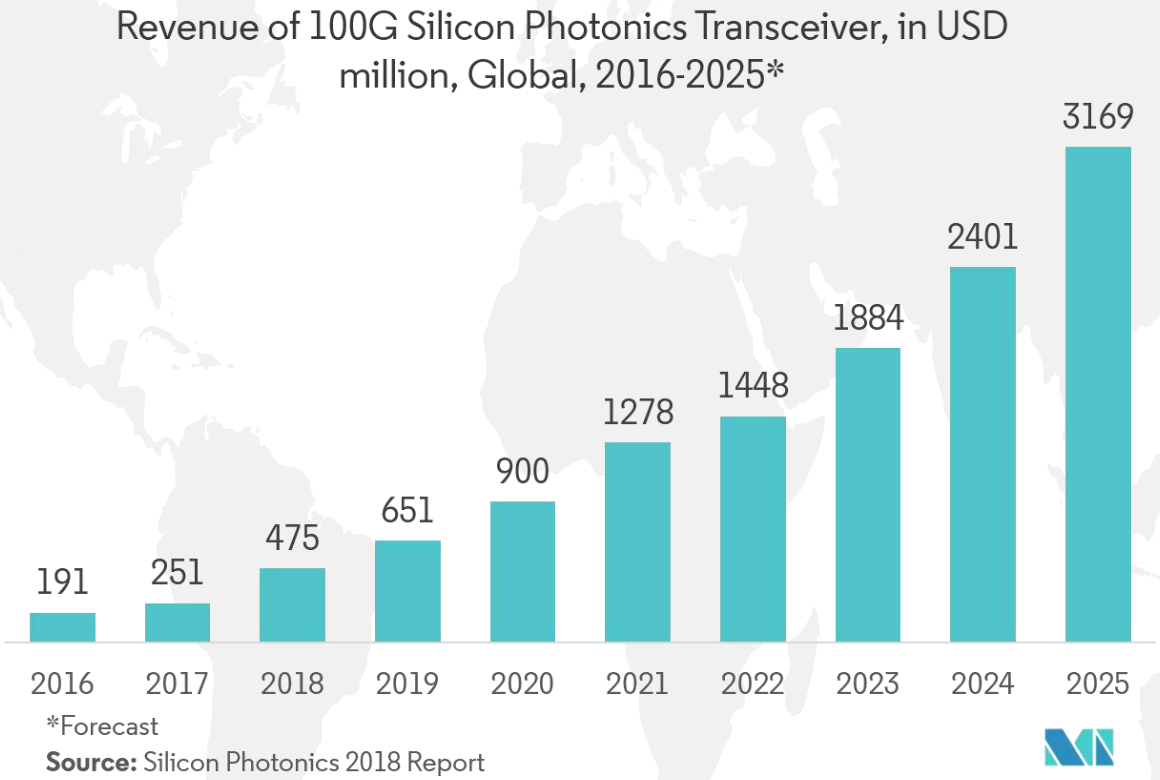






PIC and optical communication

Example of market forecast

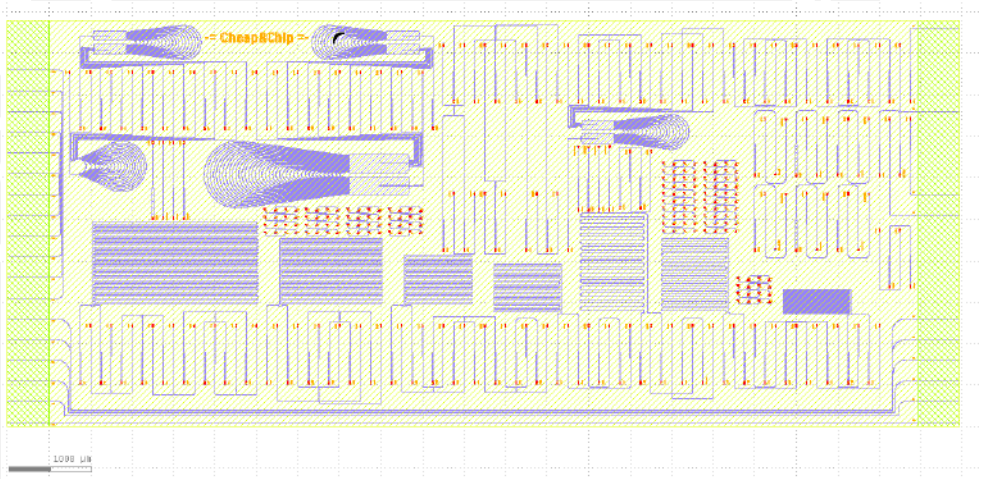


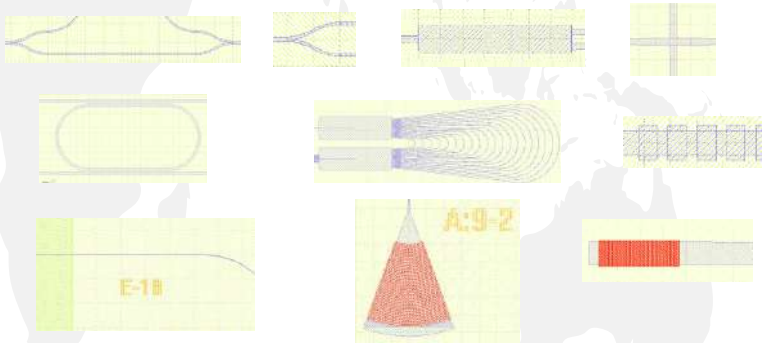
https://www.mordorintelligence.com/industry-reports/photonics-market-market

PICs - designed, fabricated, available

SOI PIC (Cornerstone) - Passive

- Y-splitter
- MZI + delay line
- Delay lines
- Directional coupler (50/50; 90/10)
- MMI: 1x2; 2x2; 3x3
- Crossing
- Racetrack resonator
- Bragg grating (filter)
- AWG (4 types)
- Couplers
- Grating couplers
- Vertical / edge
- Edge couplers

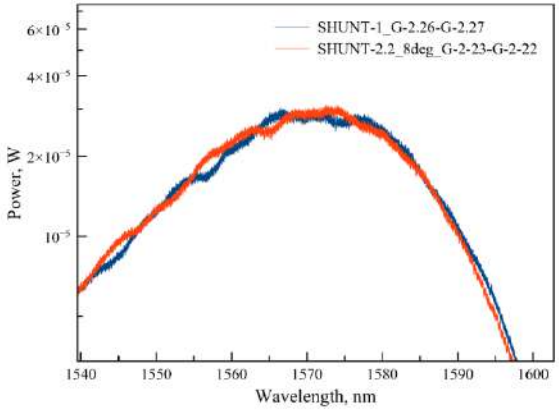


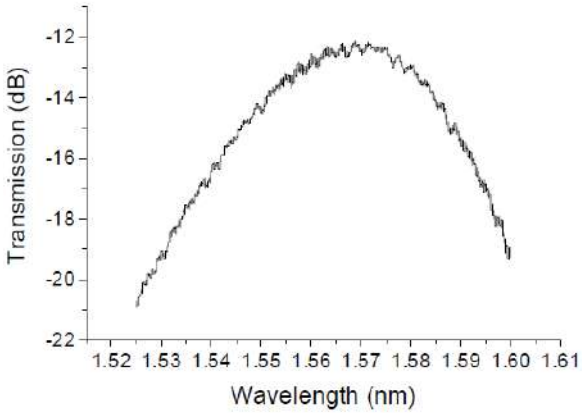


PICs - designed, fabricated, available

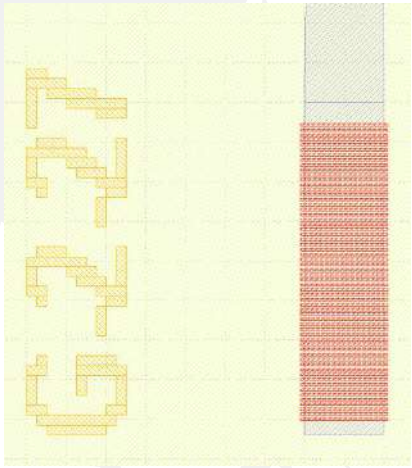
SOI PIC (Cornerstone) – Passives

	Experimental	From PDK
Max. efficiency	6.4 dB	5.5 – 6.5 dB
1dB bandwidth	22 nm	>35 nm
Center Wavelength	1570 nm	1550-1580 nm





Grating couplers



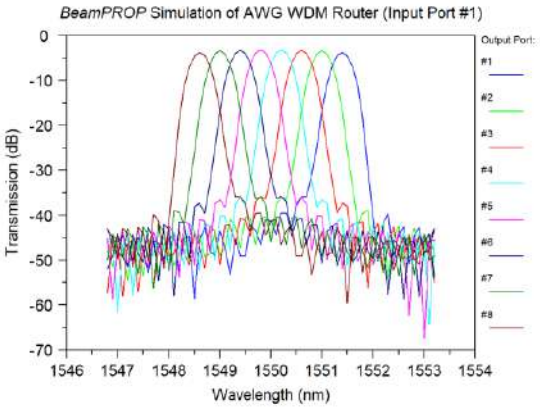
Angle was 8deg instead of 10deg

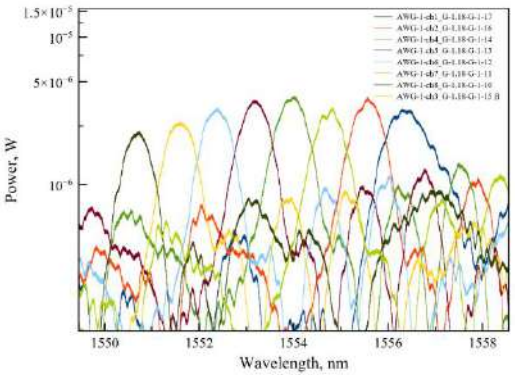
PICs - designed, fabricated, available

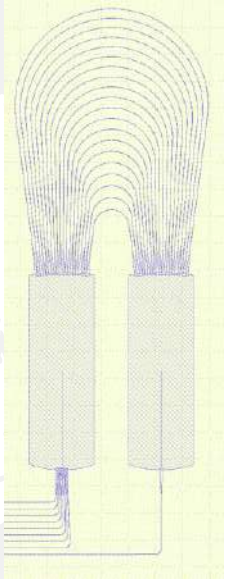
SOI PIC (Cornerstone) – Passives

AWG – 1 (high crosstalk)

	Simulated	Experimental
Channel spacing	100GHz (0.8nm)	0.801nm
Channel FWHM	100GHz (0.8nm)	0.750nm
Crosstalk	~ 3dB	~3dB
Noise floor (SMSR)	>30dB	~8dB
Central wavelength	1550	1553.5





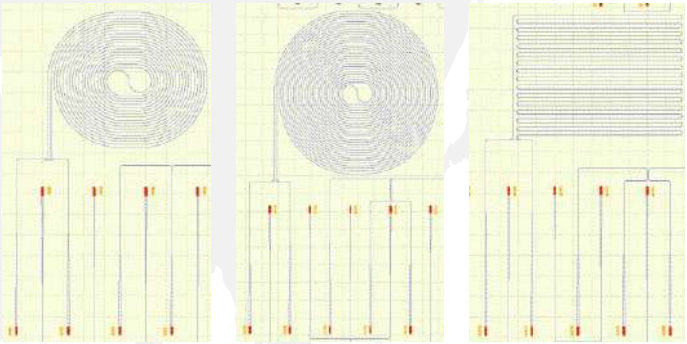


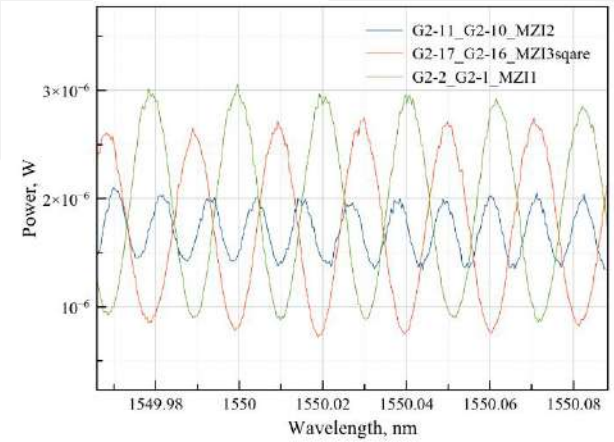
PICs - designed, fabricated, available

SOI PIC (Cornerstone) – Passives

	Delay, ps	Wg losses, dB/cm
MZI_1	392.5 ps	2.40
MZI_2	721.5 ps	3.54
MZI_3	388.8 ps	2.23

Asymmetric MZIs

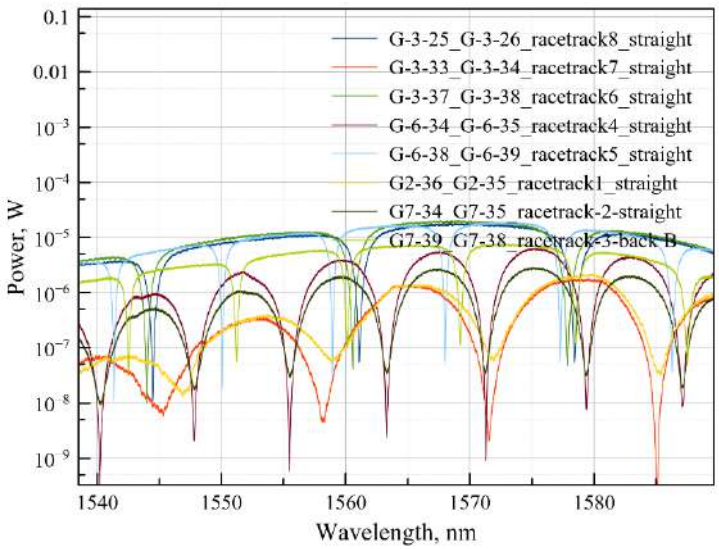




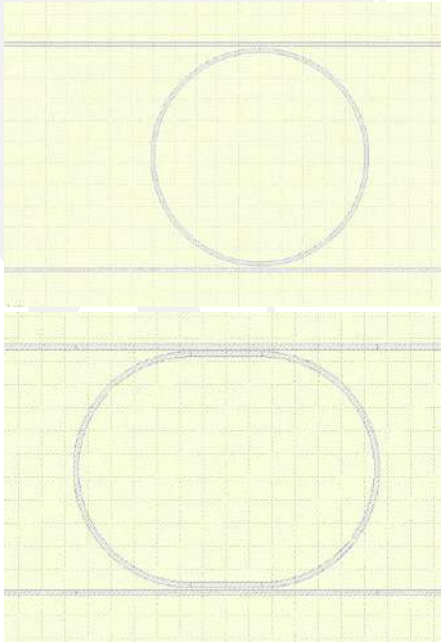
PICs - designed, fabricated, available

SOI PIC (Cornerstone) – Passives

Q-factors: ~1700 and lower



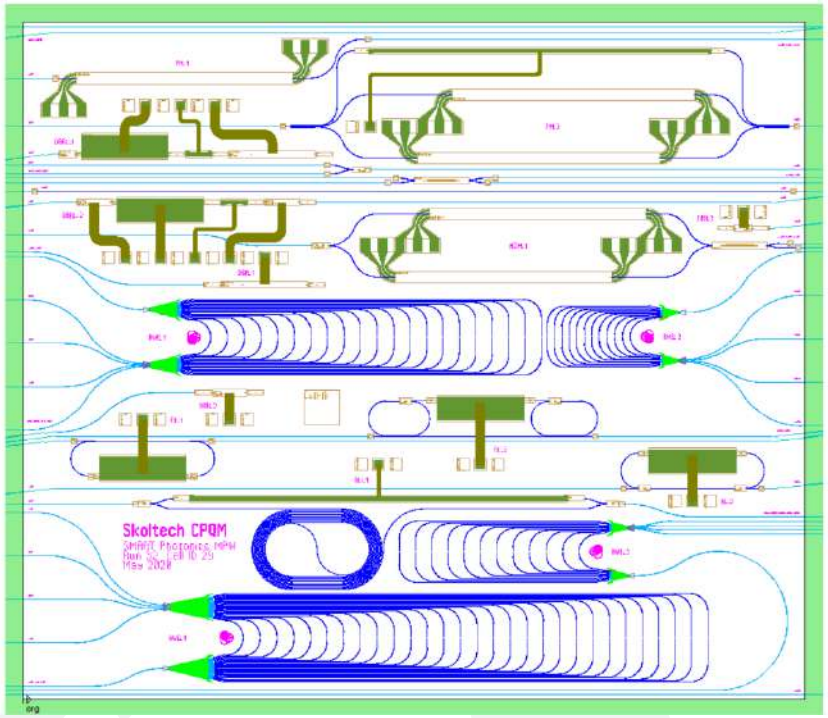
Racetrack resonators



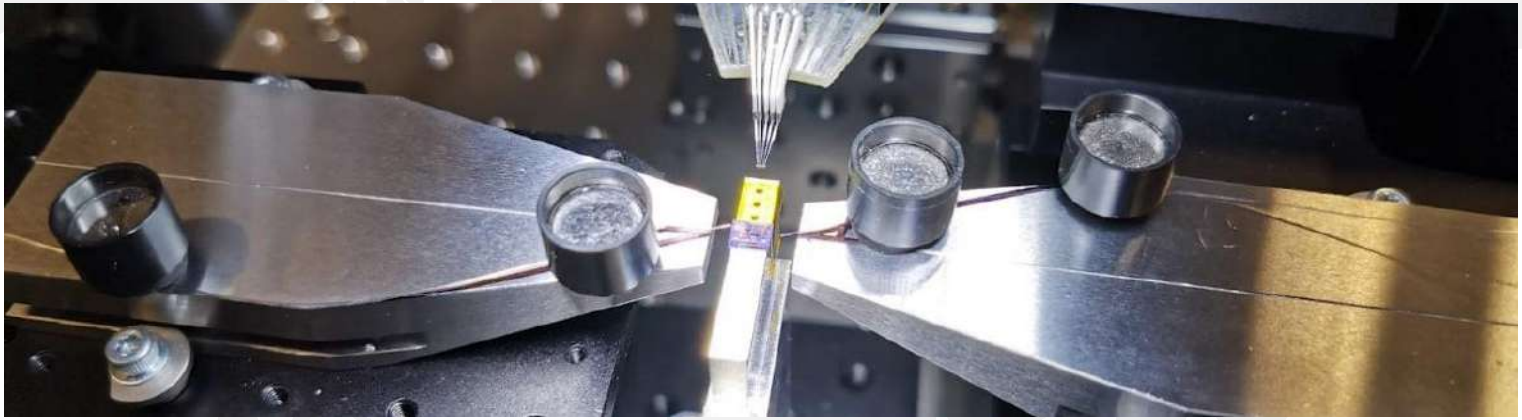
PICs - designed, fabricated, available

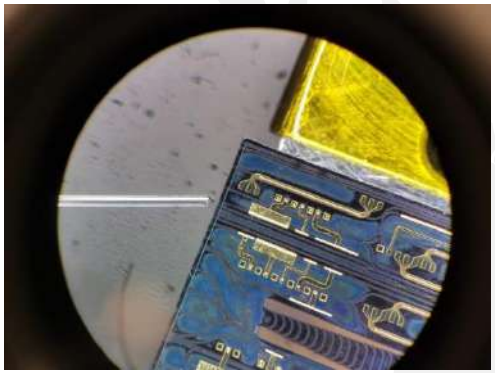
InP PIC (SMART Photonics) - Passive, Active, HF

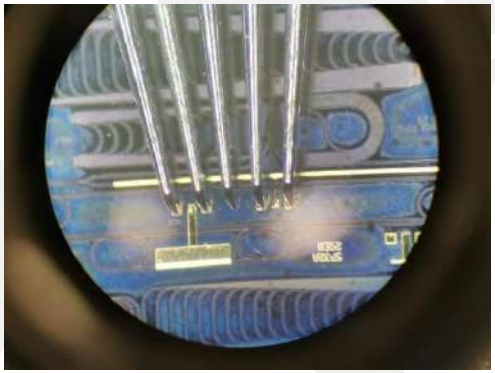
- Phase modulator 8 GHz
- Optimized amplitude modulator 8 GHz
- Triple phase modulator
- AWG (4 types)
- MZI + Delay line
- Tunable DBRs
- DBR lasers
- Ring lasers
- Passives (splitters, waveguides, etc.)
- Edge couplers

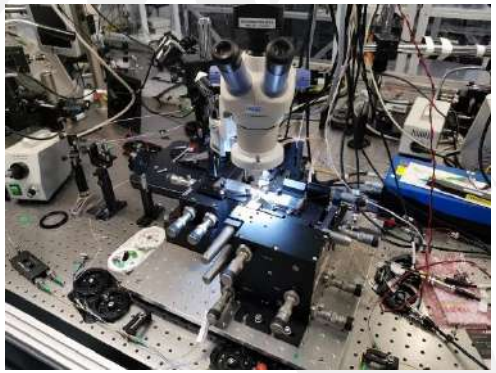


InP chip on the probe station (at RQC)









InP SMART Photonics chip on the probe station at RQC Coherent Microoptics and Radiophotonics lab

PICs - designed, fabricated, available

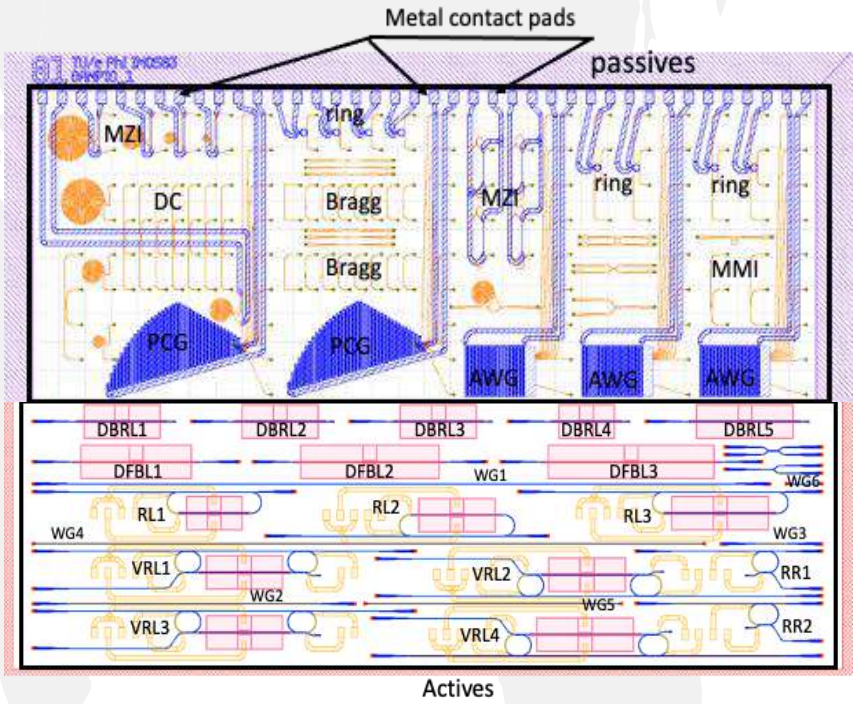
IMOS PIC (TU/e) - Passive, Active, HF

Passive + Heaters

- Waveguides / Direct couplers / Focusing couplers
- Delay lines
- MMI
- DBR
- Photonic Crystal reflector
- Ring resonators
- AWG (Arrayed Waveguide gratings)
- PCG (Planar concave gratings)
- PCG + assymtric MZI (Interrogators)

Active

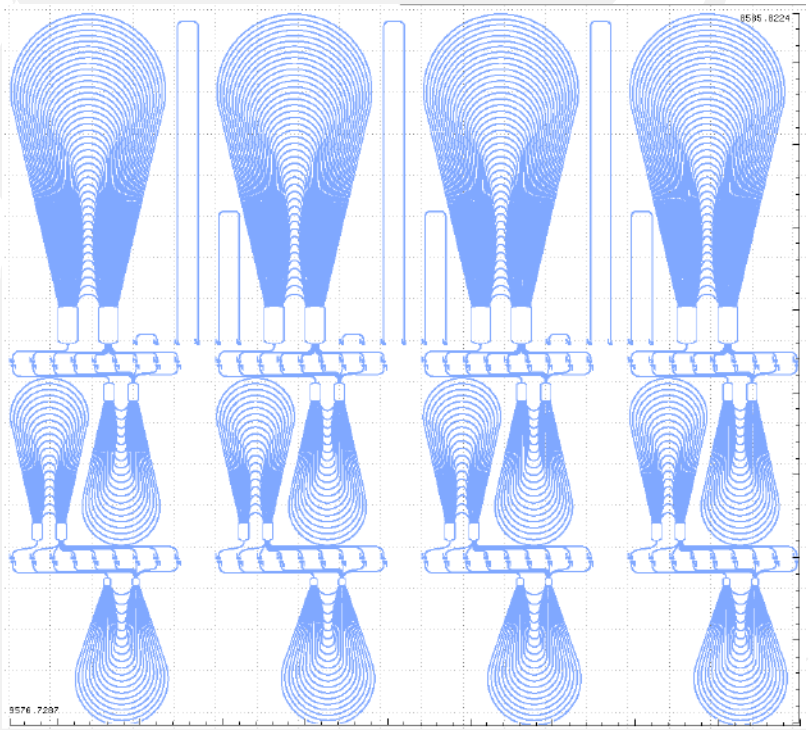
- DBR lasers
- DFB lasers
- Ring lasers
- Vernier ring lasers



PICs - designed, fabricated, available

SiN PIC (TiRphotonics) - Passive

- AWGs (4 types)
- Grating couplers
- Waveguides / Bends
- Arrays

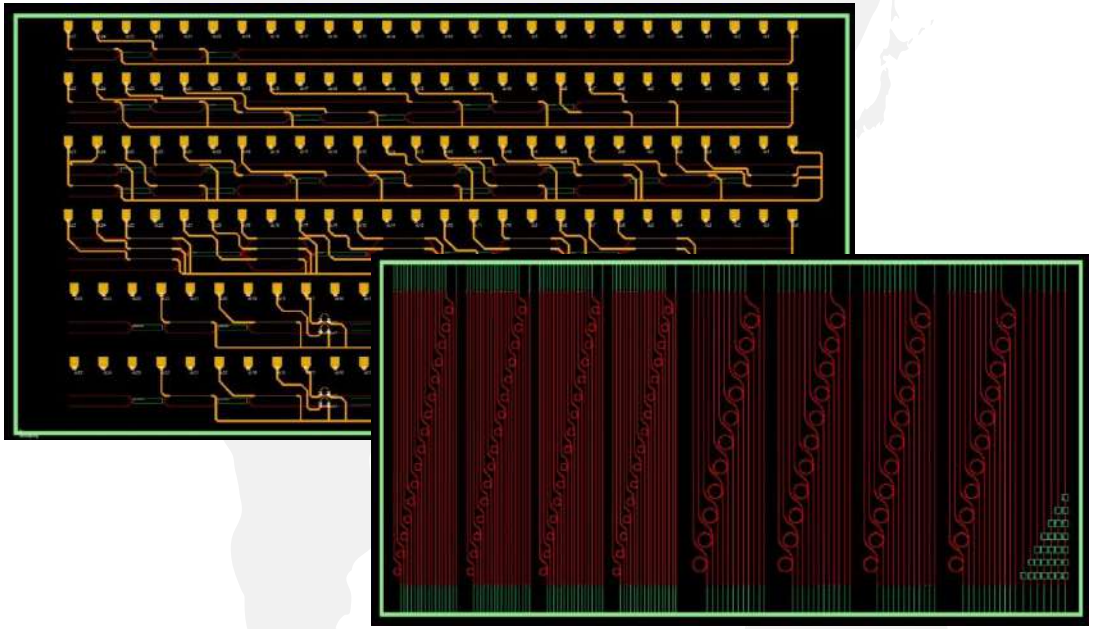


PICs - designed, fabricated, available

SiN PIC (Ligentec, Switzerland) with **RQC**

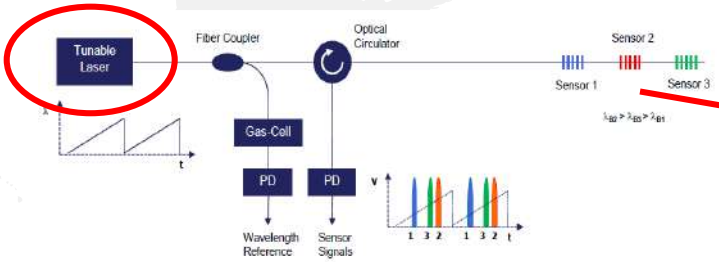
Passive + heaters:

- Waveguides
- Splitters
- MZI
- Ring resonators
- Heaters
- Cross sections



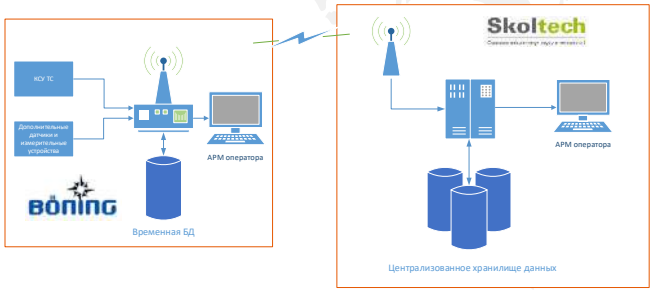
Project SHM (Structural Health Monitoring)

Propulsion sensor has been installed on rotor of ship engine.

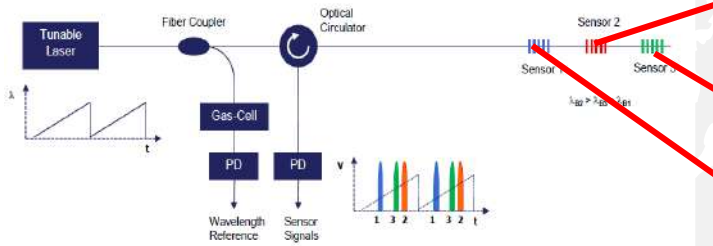


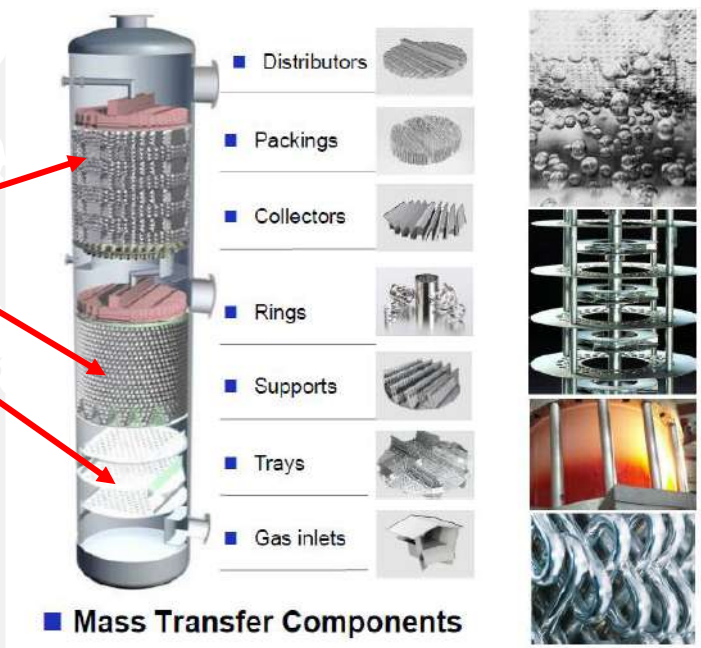
Tension/acoustic sensors have been installed on ship side from inside.

The data is trasfered and stored independently on externel server.



Project SHM on distillation tower

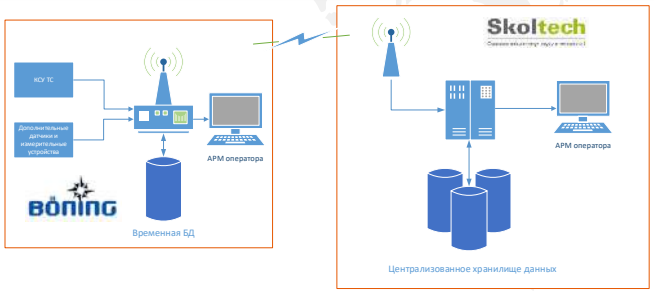




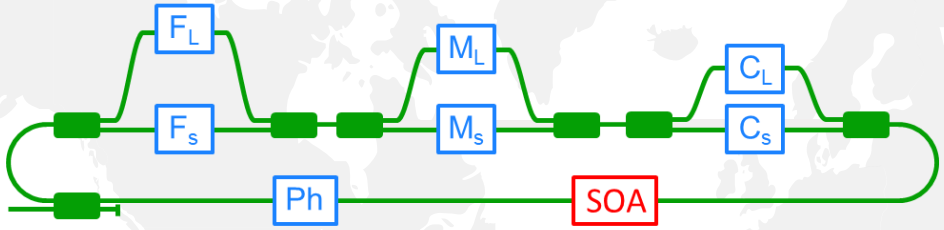
Tension/acoustic sensors have been installed inside the tower.

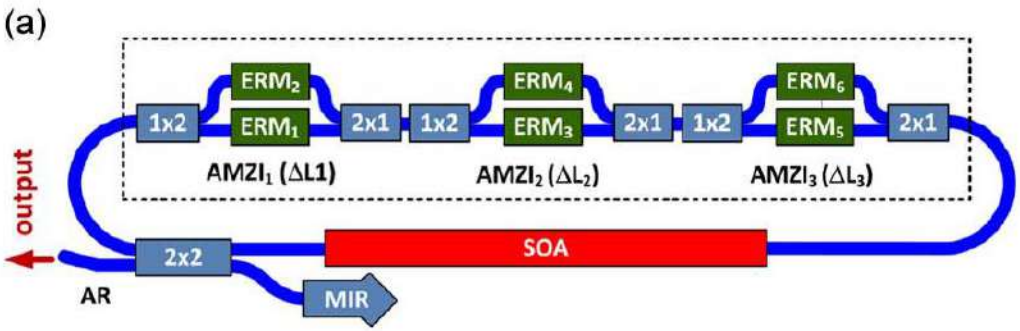
Peripheral computation based on neuromorphic PIC.

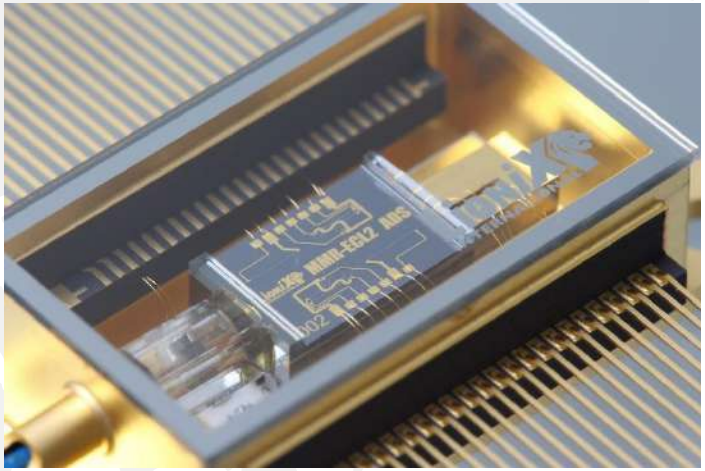
The data is trasfered and stored independently on externel server.



Project tunable laser on chip







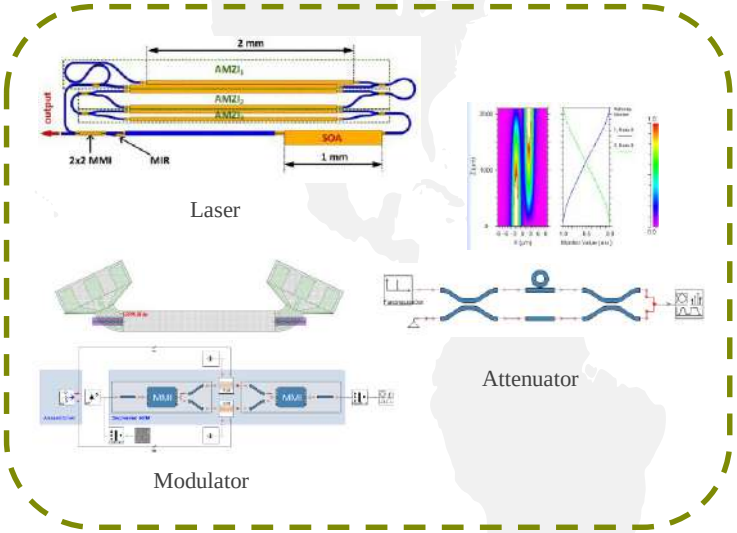
The design of the laser is based on the extended ring resonator layout. The main cavity is composed by the ring with integrated SOA, cascade of tunable AMZIs, and 2x2 MMI for coupling out the light. The cascade of AMZIs works for selecting the desired longitudinal cavity mode.

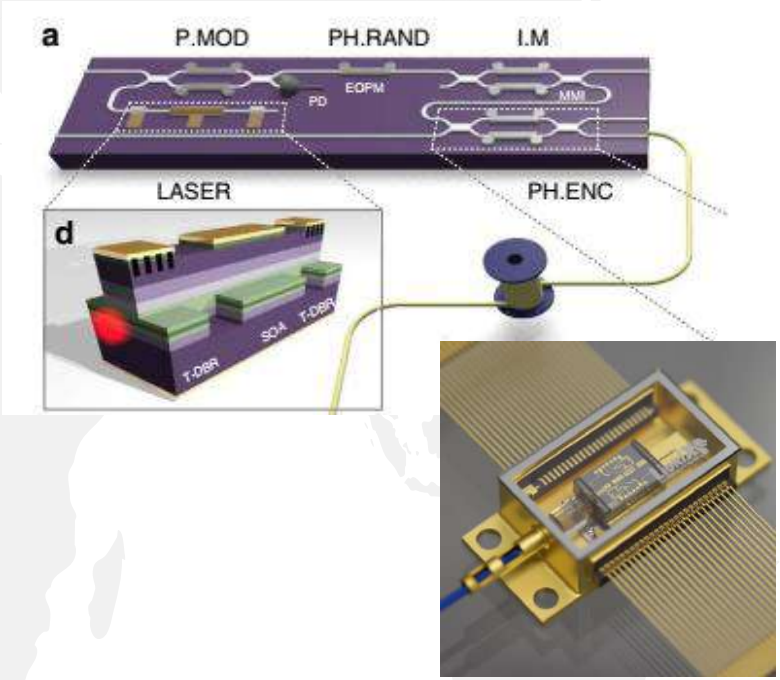
ERM – electro-refractive phase modulator
AMZI – assymetric Mach-Zender interferometer
SOA – semiconductor optical amplifier

Project QKD on chip

Alice possible solution: InP monolithic integration of all the PIC components*

*** Other technologies could be considered for enhanced structure**

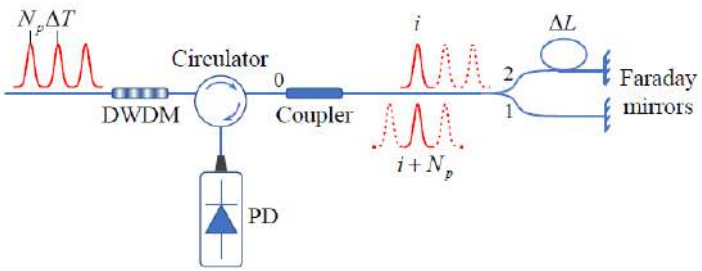




Full PIC flow – from design – to device

Project Quantum Random Number Generator on chip

1. QRNG lab tests – previous competence of RQC.
2. Design of QRNG on chip, MS using facilities of CPQM, Photonic Integrated Research Lab.
3. Design of QRNG&ADC (independent project of ADC on-chip is ongoing, MIFI).
4. Producing of PICs (Skoltech, external nanofabs) and testing (Skoltech, Photonic Integrated Research Lab).



On chip

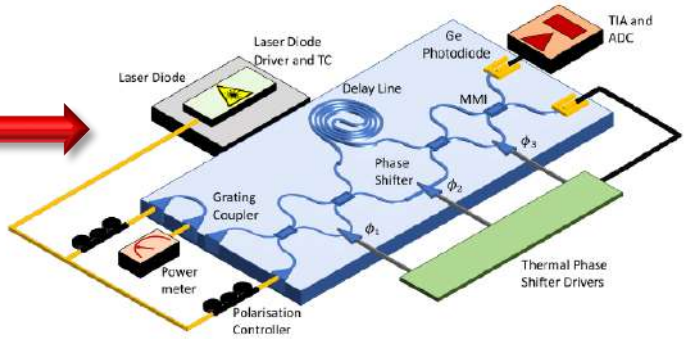


Fig. 1. The optical scheme used in this work to observe interference of laser pulses. The circulator is used to separate optical signals that travel in opposite directions and thus to prevent unwanted feedback into a laser. PD stands for the photodetector; DWDM – dense wavelength division multiplexing bandpass filter. ΔT and ΔL are defined in the text.

Francesco Raffaelli etc., „A SOI Integrated Quantum Random Number Generator Based on Phase fluctuations from a Laser Diode“, arXiv:1804.05046v1 [quant-ph] 13 Apr 2018

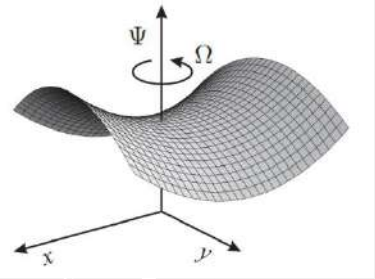
Roman Shakhovoy etc., „Influence of chirp, jitter and relaxation oscillations on laser pulse interference in optical quantum random number generator”, submitted to OE.

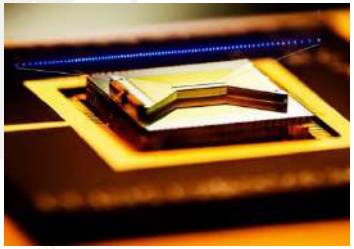
Project Atomic Clock/Networking

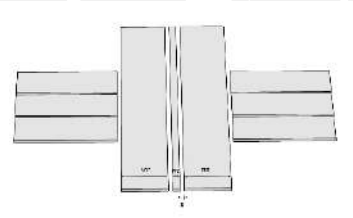
Transportable optical Yb ion frequency standard

Project has been completed in 2019. Nest steps – transition on PIC bases and onboard version.

Ion trap on a chip







Linear computation: montage of a photo of the chip containing the trapped ions and an image of the ions in a 1D array (Courtesy: Christopher Monroe).

Ion-based commercial quantum computer is a first, Physics World, 17 Dec 2018.

https://physicsworld.com/a/ion-based-commercial-quantum-computer-is-a-first/

ECOPIC – **ECO**system of **P**hotonic **I**ntegrated **C**ircuits

Design, Fabrication, Test, and Packaging: West

ECOPIC

- Modeling & Design
- External / Internal Foundries
- Test & Measurements Packaging

SYNOPSYS, VPIphotonics, KEYSIGHT TECHNOLOGIES, Nazca design, MATLAB, python

SMART PHOTONICS, CORNERSTONE, Fraunhofer HHI, LIONIX INTERNATIONAL, LIGENTEC, TU/e Technische Universiteit Eindhoven University of Technology, Zelenograd nanotechnology center, TYCYP TUSUR UNIVERSITY, TiRphotonics

KEYSIGHT TECHNOLOGIES, MPI CORPORATION, FORMFACTOR, LUMINOS Photonics Solutions, PIXAPP Photonic Packaging Pilot Line, Technobis group, OZ Optics, phix

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SILVACO
EM3DS
PRIMARIUS
Nazca design
Meep
Star Photonics
python

ZHIWEI Photonics
InP Photonic Integrated Circuits Foundry
SITRI 上海微技术工业研究院
Shanghai Industrial Technology Research Institute
TOWERJAZZ
dust photonics
Star Photonics
浙江光特科技有限公司
Zhejiang Guangte Technology Co.,Ltd
IMECAS 中国科学院微电子研究所
Institute of Microelectronics of Chinese Academy of Sciences

上海交大-平湖智能光电研究院
SJTU-Pinghu Institute of Intelligent Optoelectronics
Ceyear
RIGOL Beyond Measure
Teramount
comstar
BECKERMUS The Art of Technology
TABOR ELECTRONICS
DIMENSION TECHNOLOGY SYSTEM

ECOPIC – **ECO**system of **P**hotonic **I**ntegrated **C**ircuits

Commercial cooperation in the frame of ECOPIC

- It is expected that **SME becomes a major partner of ECOPIC**. Main cooperation SME-Design Center does not exclude interaction SME-NANOFAB, especially for standard samples with PDK.
- **Enterprises cooperate mainly with SME**, which does not exclude cooperation with SME and ECOPIC directly.