ECOPIC – ECOsystem for Photonic Integrated Circuits

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Skoltech – structures and goals

- Molecular and Cellular Biology
- Neurobiology and Brain Rehabilitation
- Petroleum Science and Engineering
- Photonics Science and Engineering
- Material Technology
- Energy Science and Technology
- Digital Engineering
- Engineering Physics
- Artificial Intelligence Technology
- Advanced Studies

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ECOPIC – ECOsystem of Photonic Integrated Circuits
Discrete photonics → Semiconductor based PIC

Future of photonic – nomenclature of PICs

Microelectronics

Discrete electronics → Modern microelectronics based on integrated circuits - ICs

Photronics

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

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Applications / Markets vs. Technologies

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

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Photonics and optical communication

Electric cables – low frequencies, short distances for high frequencies

Optical fibers – high frequencies, unlimited distances
PIC and optical communication

Transmitter (Modulator +) + Receiver = Transceiver

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PIC and optical communication

Example of market forecast

Revenue of 100G Silicon Photonics Transceiver, in USD million, Global, 2016-2025*

*Forecast
Source: Silicon Photonics 2018 Report

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

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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
**SOI PIC (Cornerstone) – Passives**

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>From PDK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. efficiency</td>
<td>6.4 dB</td>
<td>5.5 – 6.5 dB</td>
</tr>
<tr>
<td>1dB bandwidth</td>
<td>22 nm</td>
<td>&gt;35 nm</td>
</tr>
<tr>
<td>Center Wavelength</td>
<td>1570 nm</td>
<td>1550-1580 nm</td>
</tr>
</tbody>
</table>

Grating couplers

Angle was 8deg instead of 10deg

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PICs - designed, fabricated, available

SOI PIC (Cornerstone) – Passives

<table>
<thead>
<tr>
<th></th>
<th>Simulated</th>
<th>Experimental</th>
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</thead>
<tbody>
<tr>
<td>Channel spacing</td>
<td>100GHz (0.8nm)</td>
<td>0.801nm</td>
</tr>
<tr>
<td>Channel FWHM</td>
<td>100GHz (0.8nm)</td>
<td>0.750nm</td>
</tr>
<tr>
<td>Crosstalk</td>
<td>~ 3dB</td>
<td>~3dB</td>
</tr>
<tr>
<td>Noise floor (SMSR)</td>
<td>&gt;30dB</td>
<td>~8dB</td>
</tr>
<tr>
<td>Central wavelength</td>
<td>1550</td>
<td>1553.5</td>
</tr>
</tbody>
</table>

AWG – 1 (high crosstalk)

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PICs - designed, fabricated, available

SOI PIC (Cornerstone) – Passives

<table>
<thead>
<tr>
<th></th>
<th>Delay, ps</th>
<th>Wg losses, dB/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>MZI_1</td>
<td>392.5 ps</td>
<td>2.40</td>
</tr>
<tr>
<td>MZI_2</td>
<td>721.5 ps</td>
<td>3.54</td>
</tr>
<tr>
<td>MZI_3</td>
<td>388.8 ps</td>
<td>2.23</td>
</tr>
</tbody>
</table>

Asymmetric MZIs
PICs - designed, fabricated, available

SOI PIC (Cornerstone) – Passives

Q-factors: ~1700 and lower

Racetrack resonators

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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
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
SiN PIC (Ligentec, Switzerland) with RQC

**Passive + heaters:**
- Waveguides
- Splitters
- MZI
- Ring resonators
- Heaters
- Cross sections

PICs - designed, fabricated, available
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 transferred and stored independently on external server.
Tension/acoustic sensors have been installed inside the tower.
Peripheral computation based on neuromorphic PIC.

The data is transferred and stored independently on external server.
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

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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
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).

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. $\Delta T$ and $\Delta L$ are defined in the text.


Roman Shakhovoy etc., „Influence of chirp, jitter and relaxation oscillations on laser pulse interference in optical quantum random number generator“, submitted to OE.
Transportable optical Yb ion frequency standard

Project Atomic Clock/Networking

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/

Project has been completed in 2019. Next steps – transition on PIC bases and onboard version.
ECOPIC – ECOsystem of Photonic Integrated Circuits

Design, Fabrication, Test, and Packaging: West

Modeling & Design

External / Internal Foundries

Test & Measurements Packaging

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ECOPIC – ECOsystem of Photonic Integrated Circuits

Design, Fabrication, Test, and Packaging: East

ECOPIC

Modeling & Design

External / Internal Foundries

Test & Measurements Packaging

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ECOPIC – ECOsystem of Photonic Integrated Circuits

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.

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