



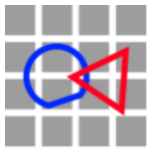
Integrated Photonics for Quantum Computing

- What can a Research Foundry do?

Rijil Thomas

Researcher, Nanophotonics

AMO GmbH



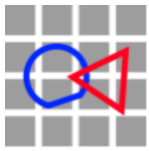
Company Profile: Overview



Gesellschaft für Angewandte Mikro- und Optoelektronik mbH

Managing Directors:

- Prof. Max Lemme
- Dr. Michael Hornung



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Gesellschaft für Angewandte Mikro- und Optoelektronik mbH

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- **High-Tech SME (non-profit) Research Foundry**
- Close ties to RWTH Aachen University
- Operating since 1997



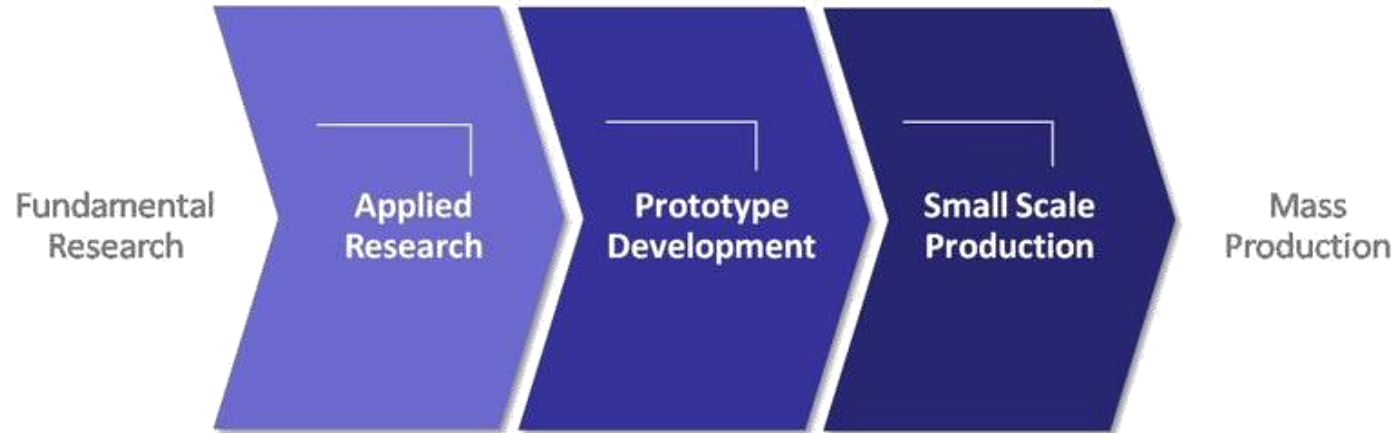
- **400 m² clean room**
- **~75 staff members**

Key Technologies:

- Silicon technology base
- Nanofabrication (NIL, E-Beam, IL, Projection)
- New materials integration
(high-k/metal gate, graphene / 2D, perovskite)

Commercial Foundry Services at AMO

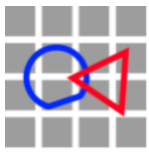
Get Access to AMO's Silicon Photonics Technology



Our Strengths

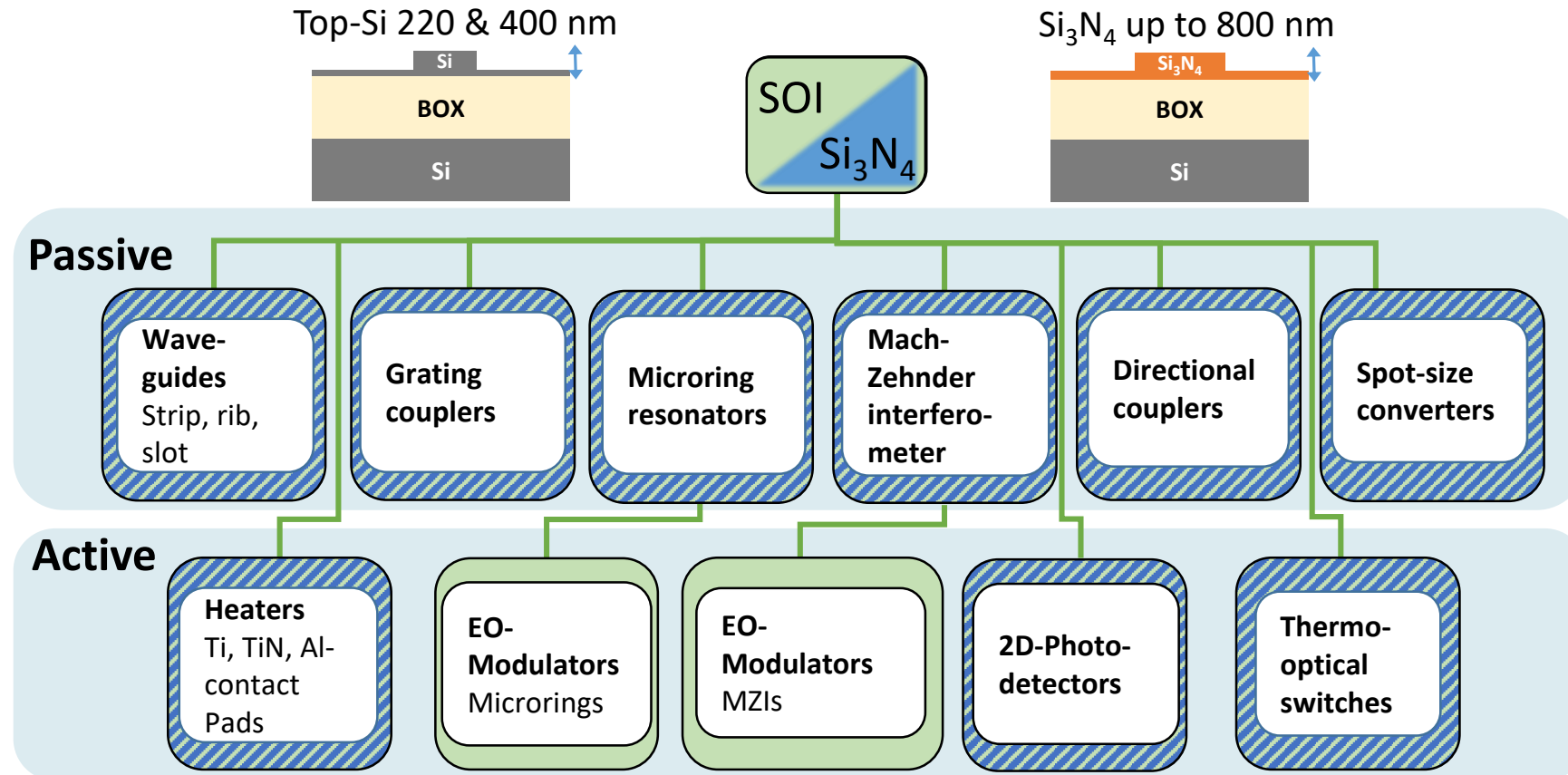
- Individual service
- Customer-specific prototyping
- From small scale to volume production
- Flexible process flow
- Short turnaround
- IP protection



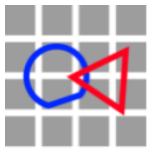


AMO's Photonics Integrated Circuit (PIC) Platforms: SOI & Silicon Nitride

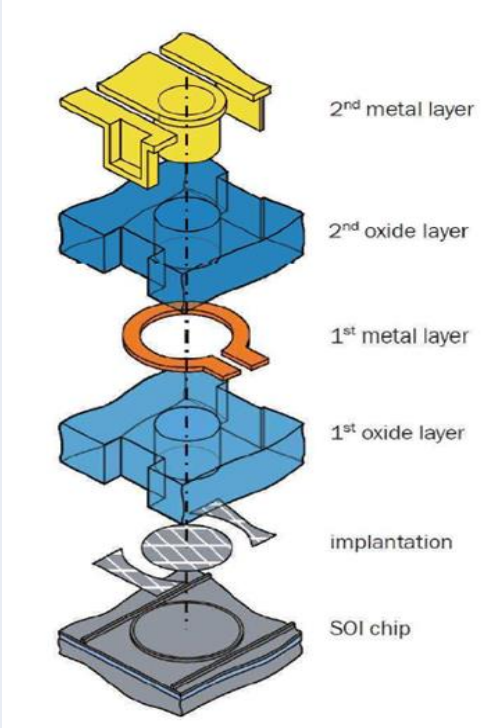
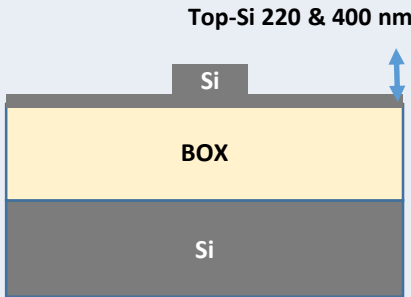
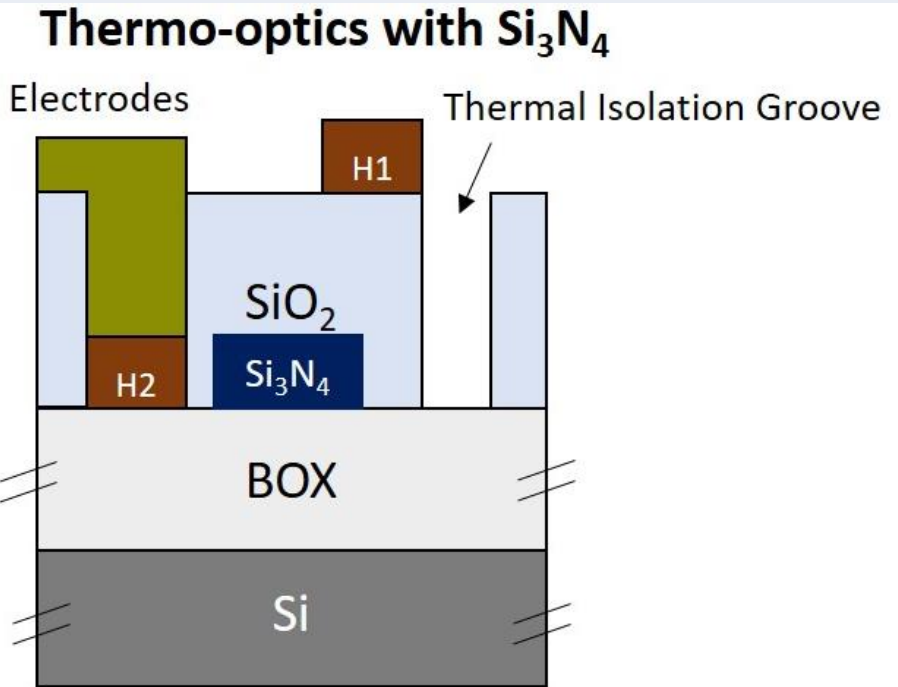
PIC Platforms at AMO



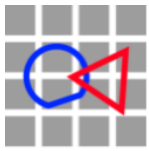
Flexible foundry platform for customized wafer runs



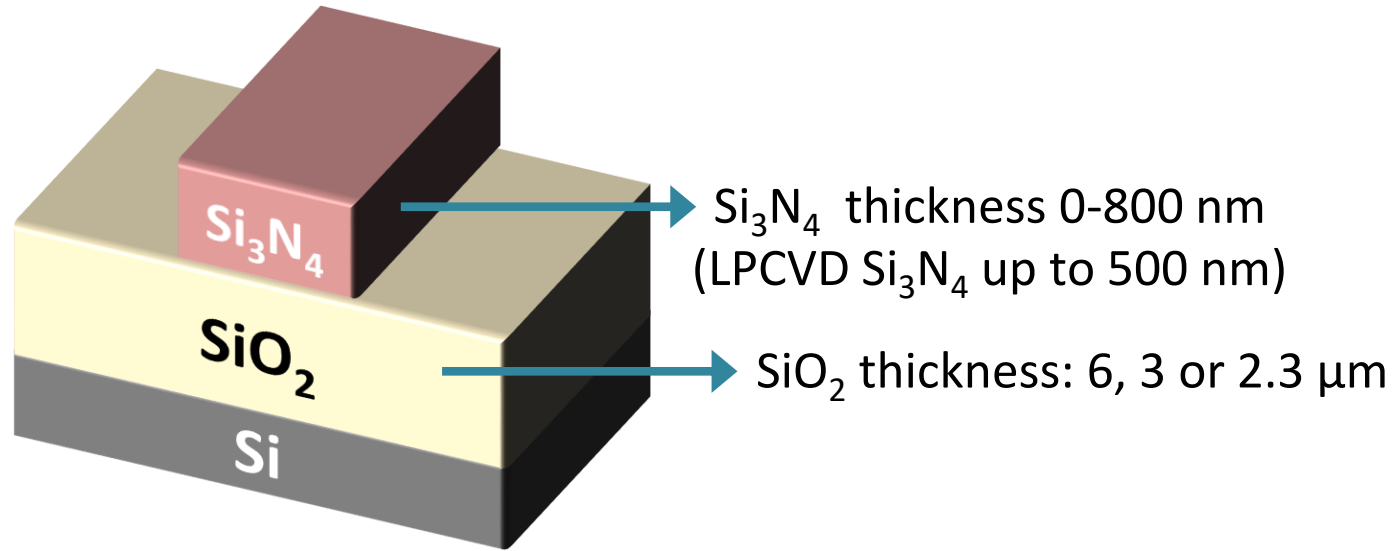
Commercial Foundry Services at AMO

Silicon on Insulator (SOI)	Silicon Nitride
<ul style="list-style-type: none">1310 nm and 1550 nm, some MIR	<ul style="list-style-type: none">Visible wavelength range to $\sim 3 \mu\text{m}$
<ul style="list-style-type: none">6" pilot-line: Active devices  	<ul style="list-style-type: none">6" pilot-line: Ultra low waveguide losses 

AMO Services

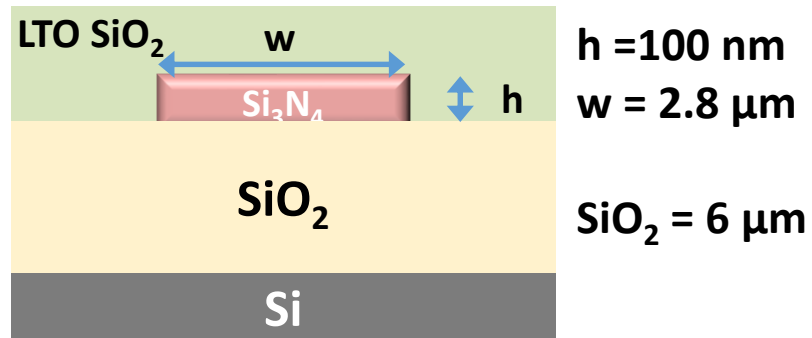


AMO's Silicon Nitride Technology

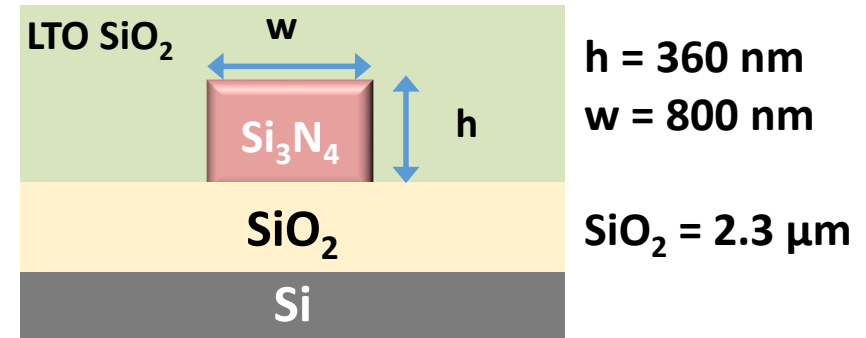


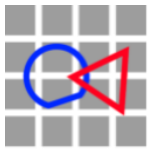
- Fabrication method: iLine stepper/EBL
- Visible wavelength also accessible
- Customizable options for:
 - Layer thickness
 - Substrate oxide thickness
 - LTO (low temperature oxide) Cladding

Waveguide Geometry 1:



Waveguide Geometry 2:

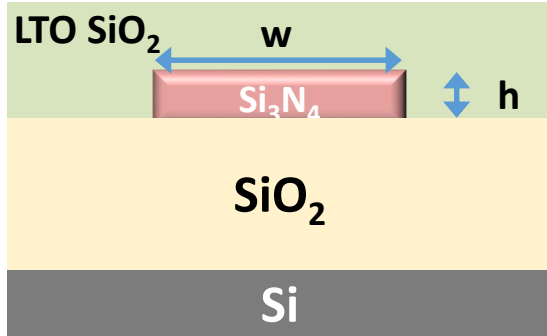




Waveguide Losses

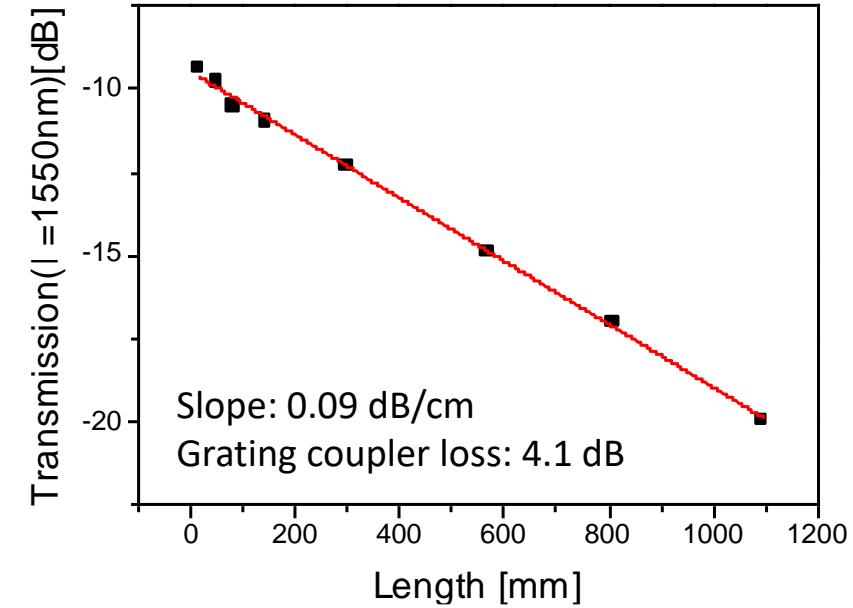
Si₃N₄ Platform

Waveguide Geometry 1:

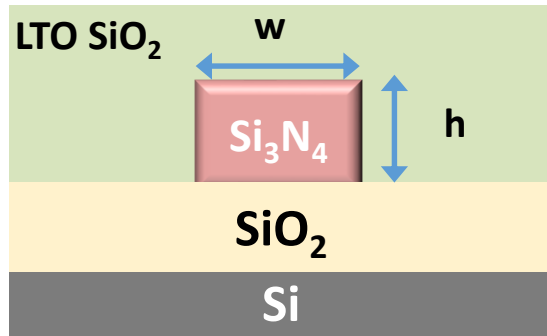


h = 100 nm
 w = 2.8 μm
 SiO₂ = 6 μm

- Ultra-low loss WG
- WG loss: ~0.10 dB/cm at 1550nm
- WG loss: ~0.05 dB/cm at 1570nm
- Grating coupler loss: ~4-5 dB

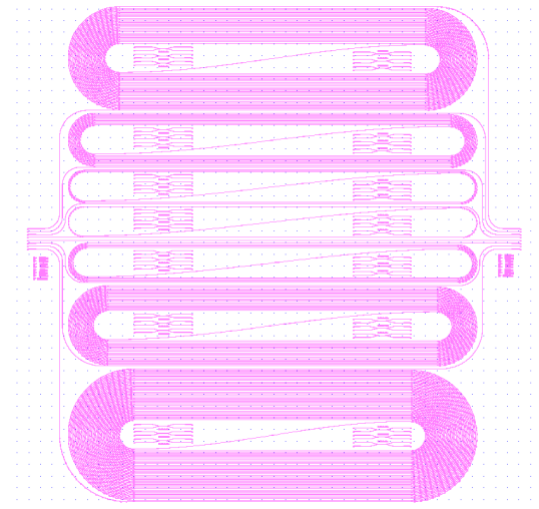


Waveguide Geometry 2:

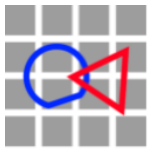


h = 360 nm
 w = 800 nm
 SiO₂ = 2.3 μm

- High confinement WG
- WG loss: ~0.5 dB/cm

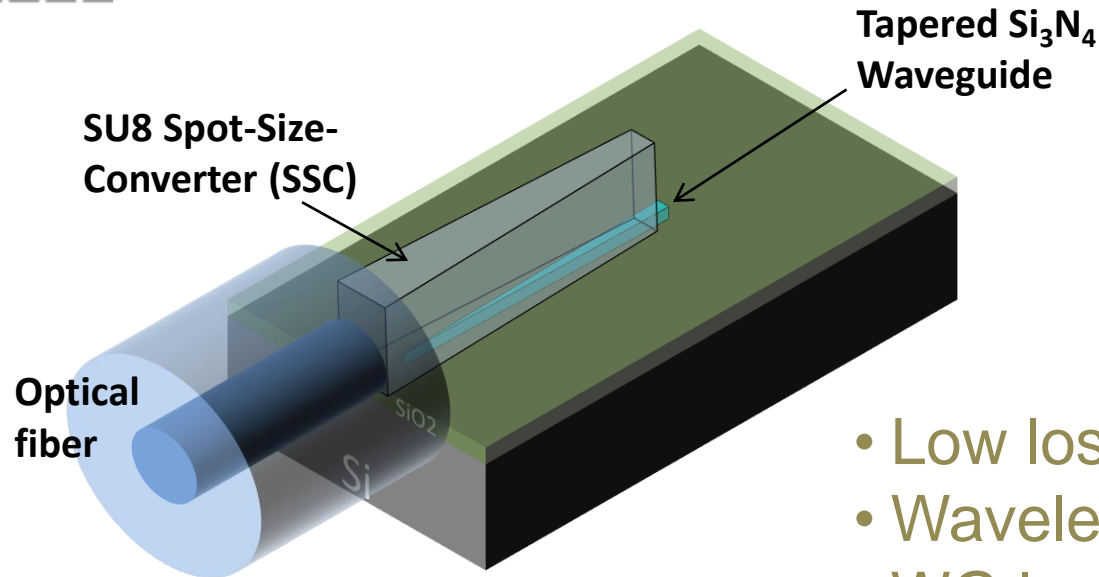


Chmielak, Bartos, et al. "High-efficiency grating coupler for an ultralow-loss Si₃N₄-based platform." *Optics Letters* 47.10 (2022): 2498-2501.

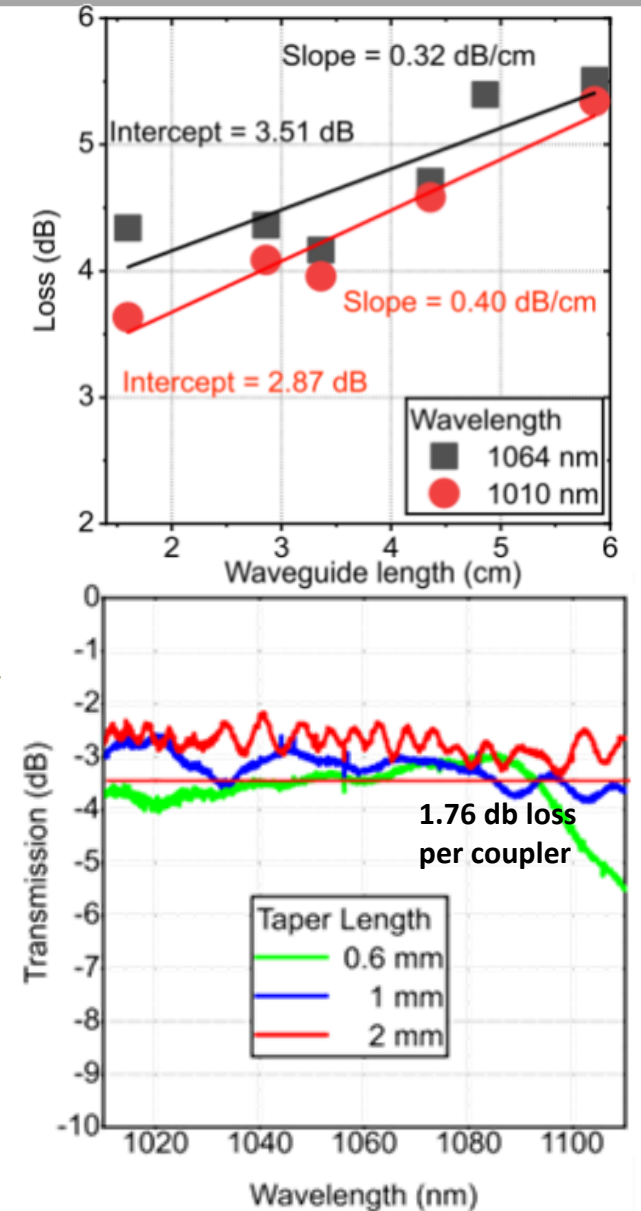
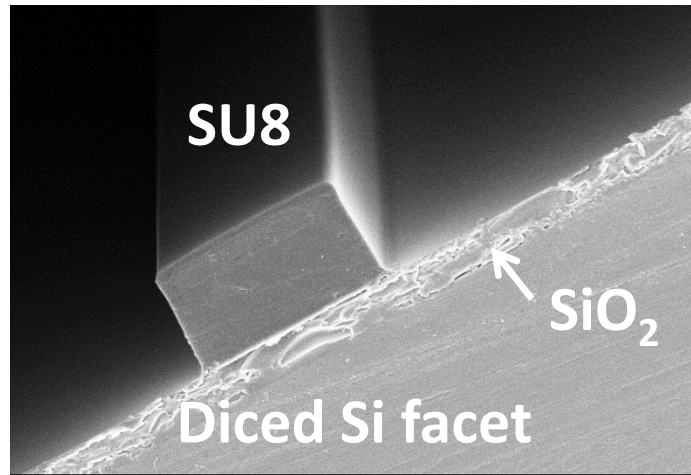


Spot-Size Converters

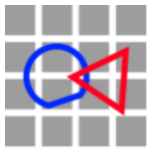
Si₃N₄ Platform



- Low loss edge coupling
- Wavelength: 1010-1110 nm
- WG loss: ~0.3-0.4 dB/cm
- Edge coupler loss: ~1.76 dB for over >100nm BW



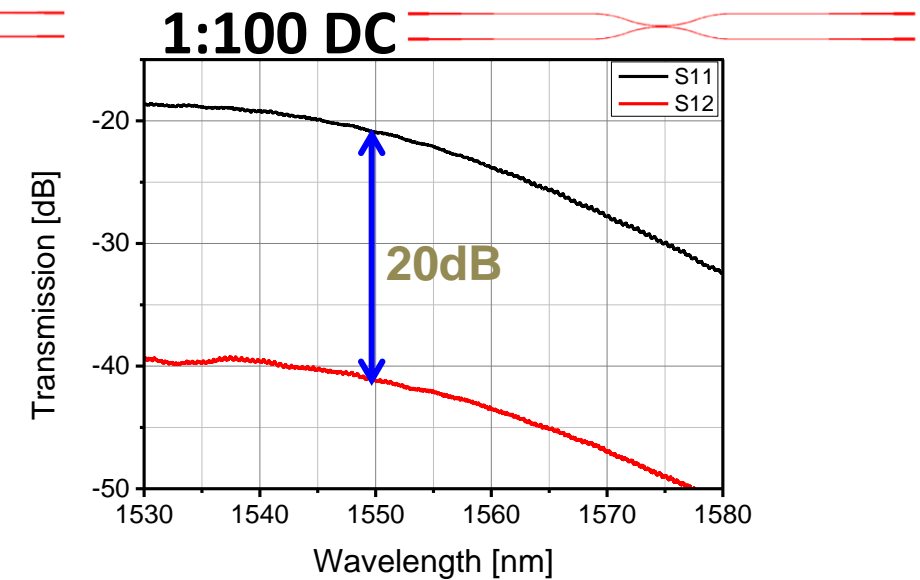
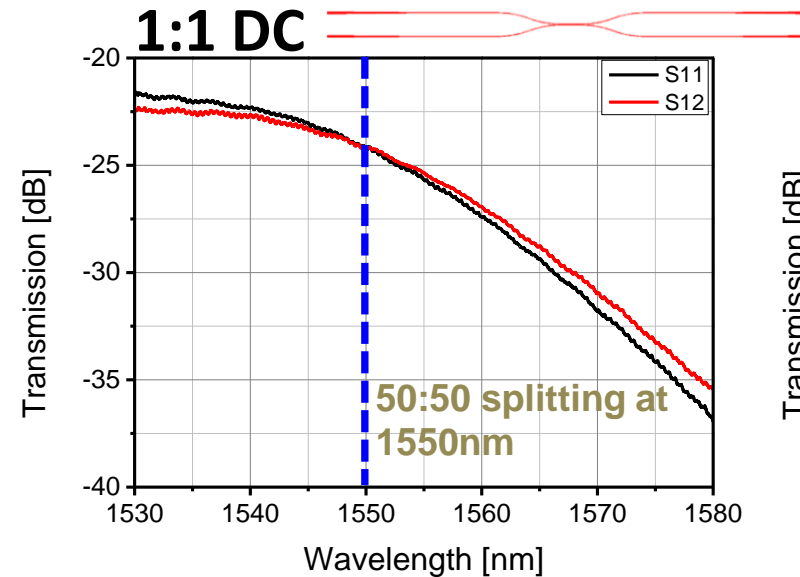
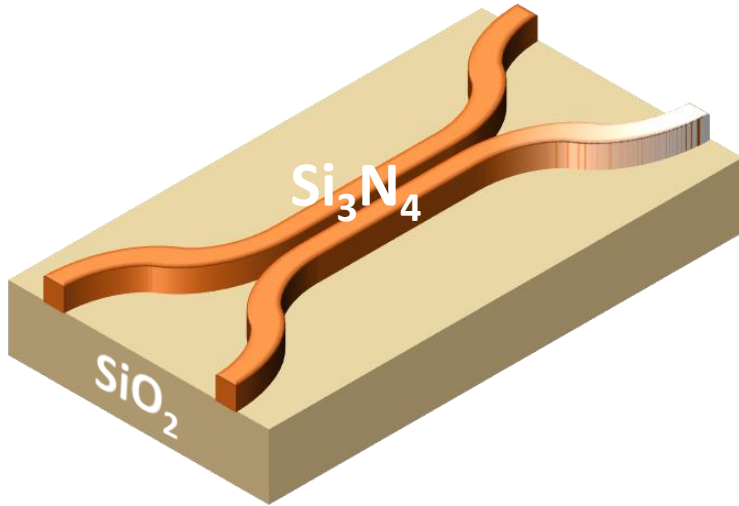
Cegielski, Piotr J., et al. "Silicon Nitride Waveguides and Spot Size Converters with < 1.76 dB Loss Over Broad Wavelength Range from 1010 nm to 1110 nm for OCT Applications." ECIO (2020)



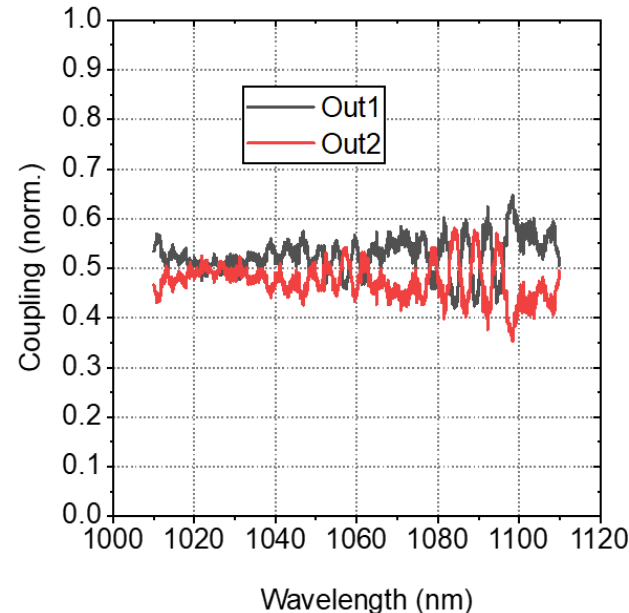
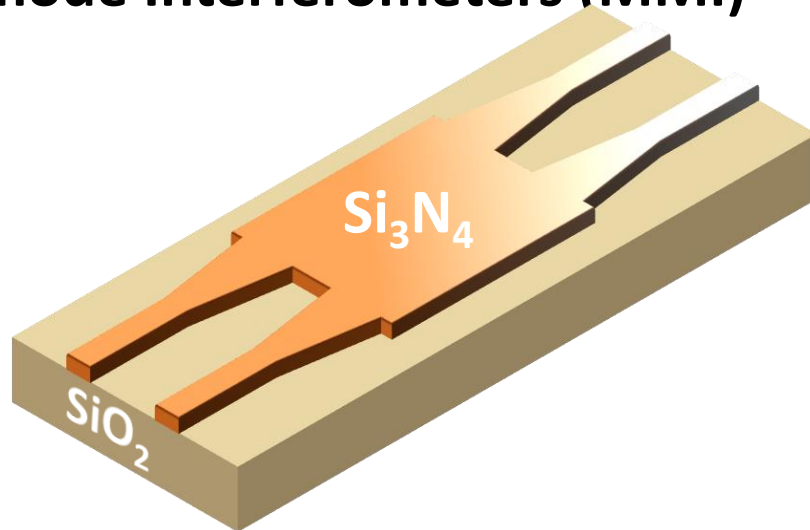
Splitters

Si₃N₄ Platform

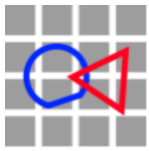
Directional Couplers (DC)



Multimode Interferometers (MMI)



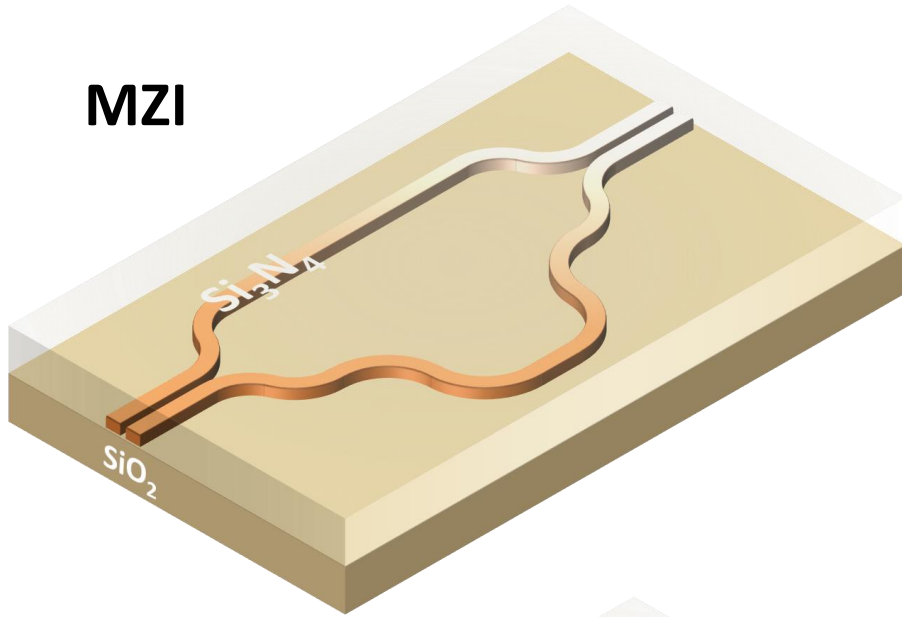
- Highly tolerant to fabrication imperfections
- Low output imbalance
- 10% loss at the band edge
- 100nm BW



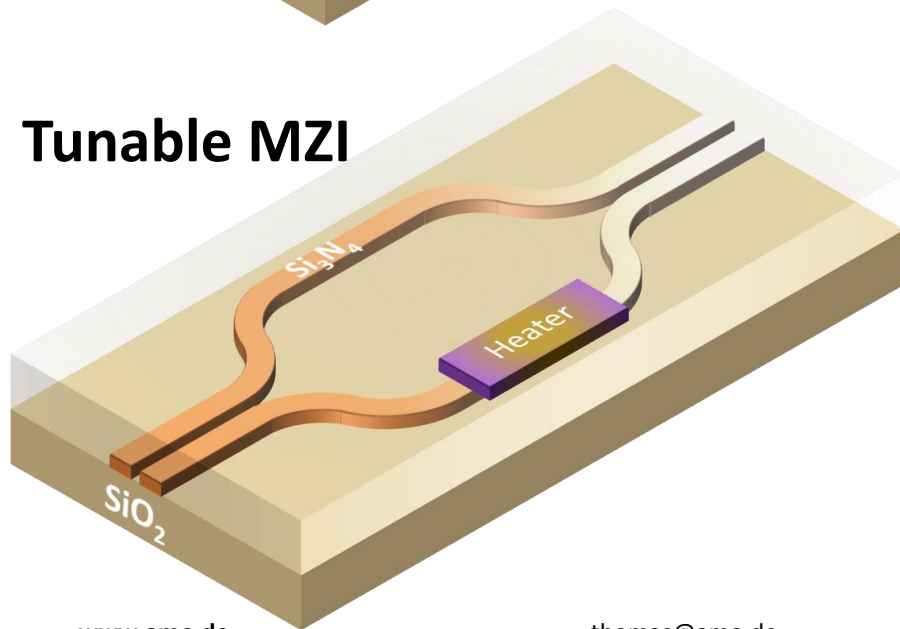
MZIs & Phase Shifters

Si₃N₄ Platform

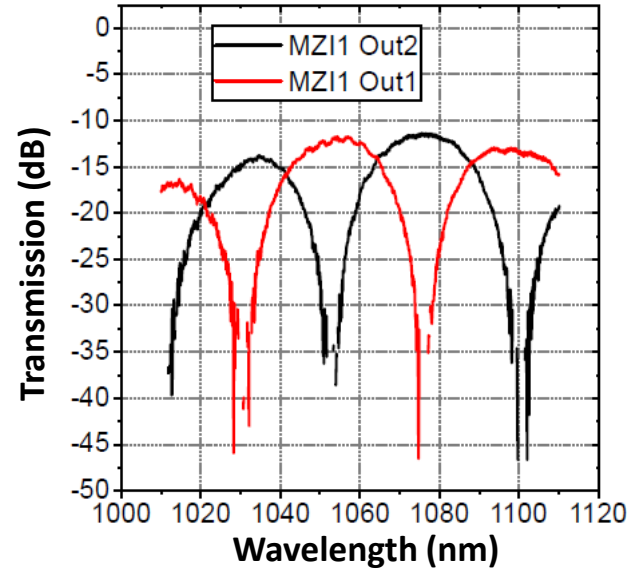
MZI



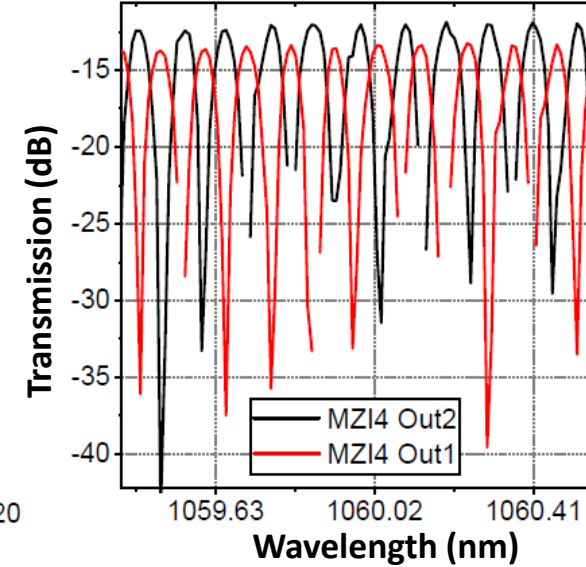
Tunable MZI



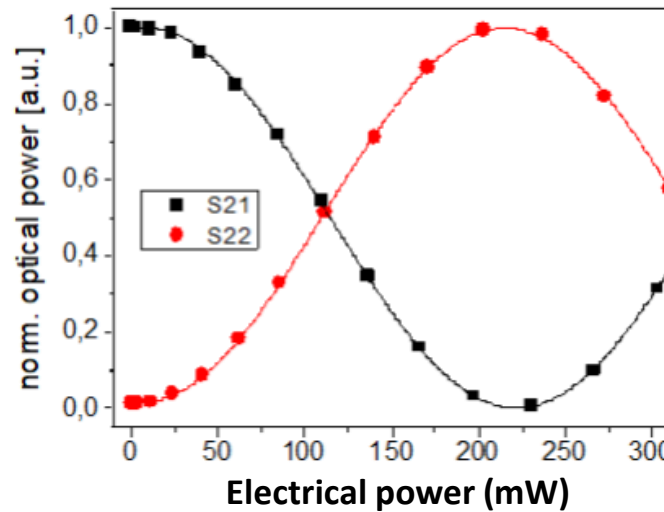
FSR 46nm



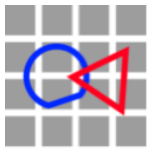
FSR 0.1nm



• ER = >30 dB

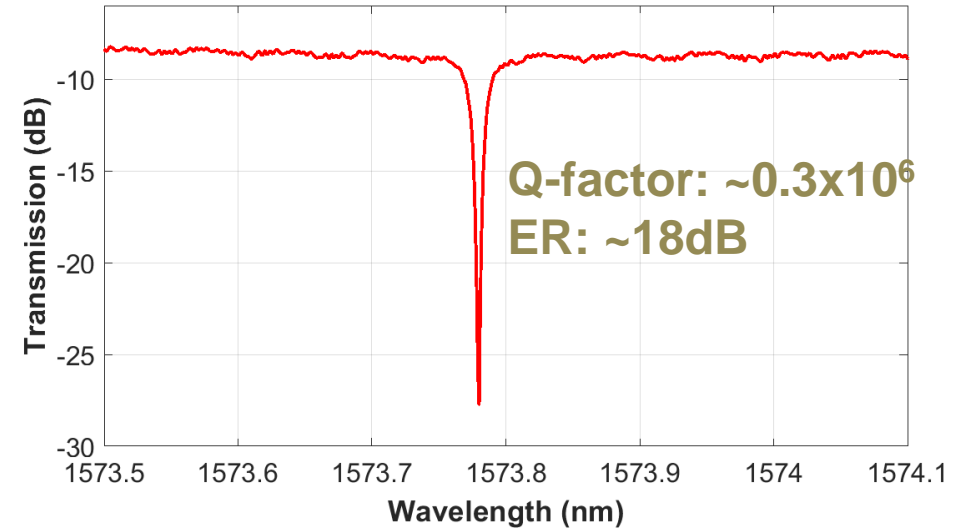
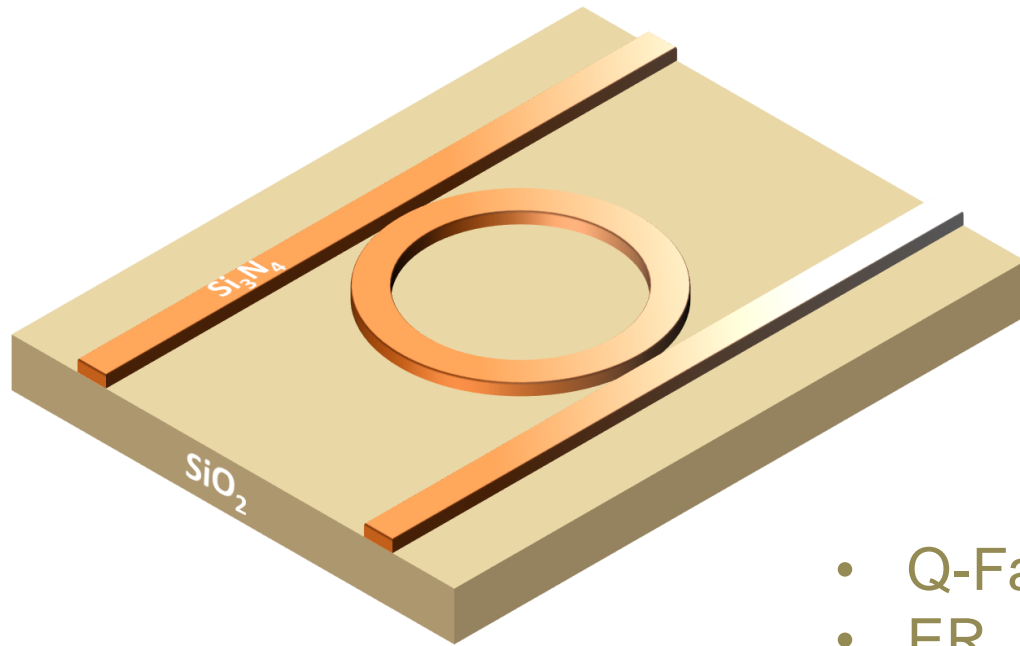


- Thermo-optical switching with Mach-Zehnder Interferometers
- Power for π shift = 220 mW
- ER = >30 dB

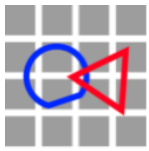


Ring Resonator

Si₃N₄ Platform

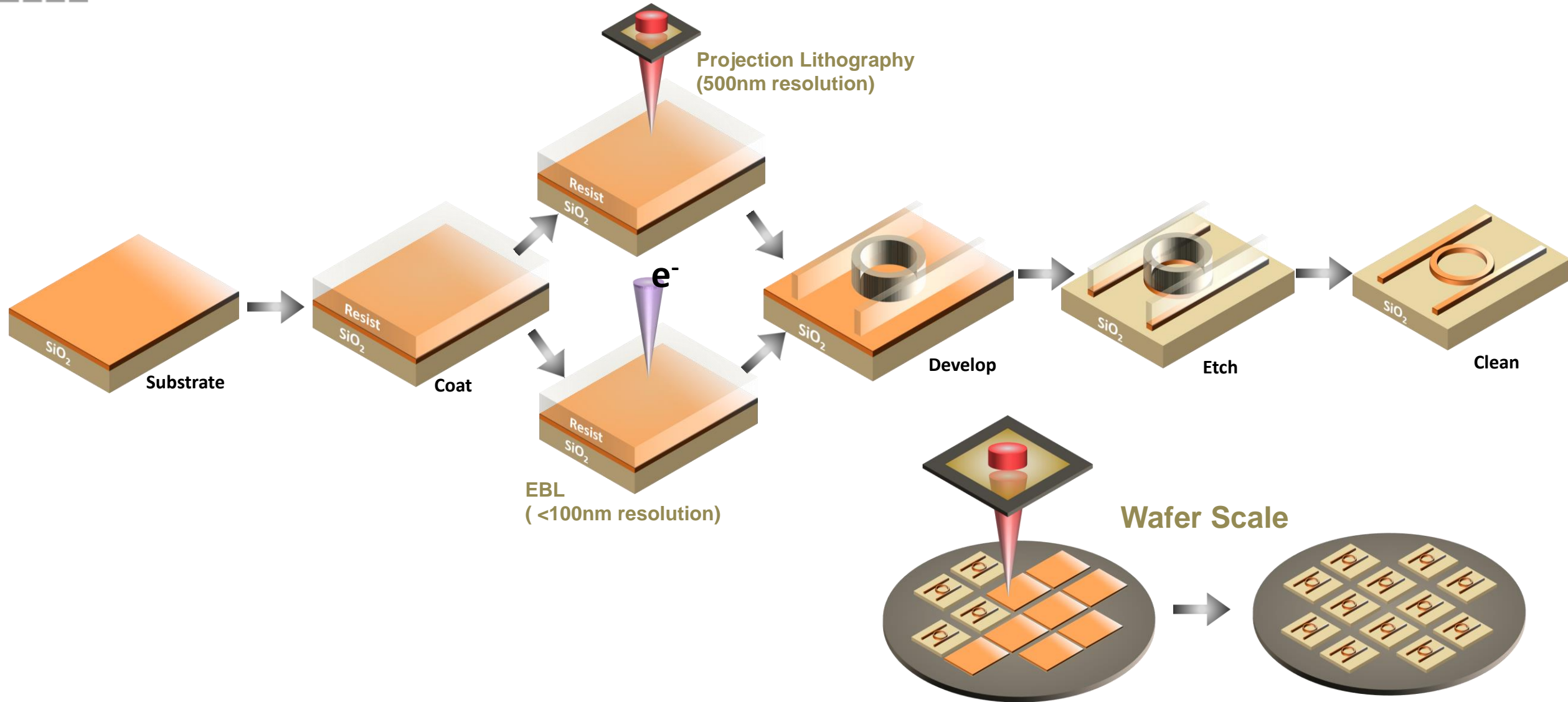


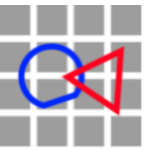
- Q-Factor: $0.2-0.6 \times 10^6$
- ER > 10dB
- Radius: 50-100 μ m



Technology - Integration

Si₃N₄ Platform





Trapped Ion Qubits Quantum Computer

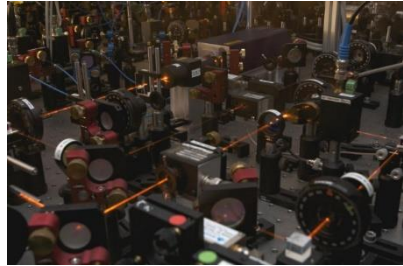
Project
ATIQ



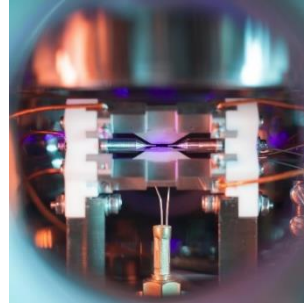
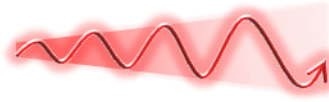
Bundesministerium
für Bildung
und Forschung



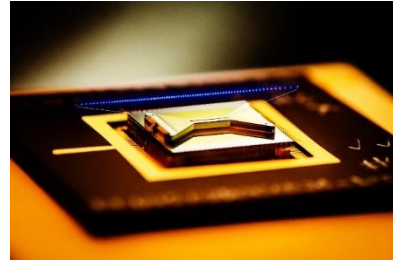
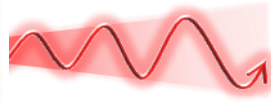
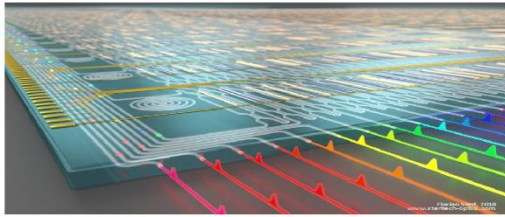
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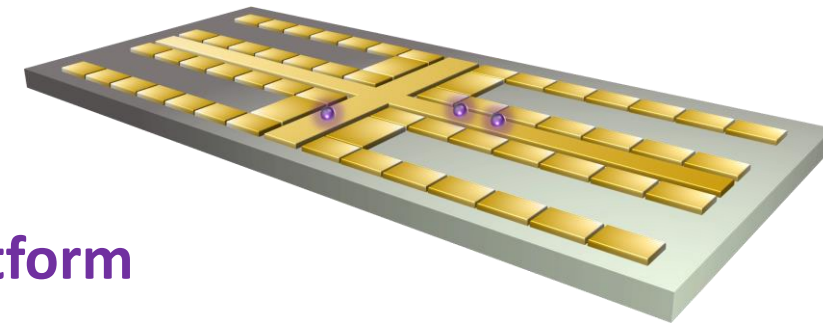
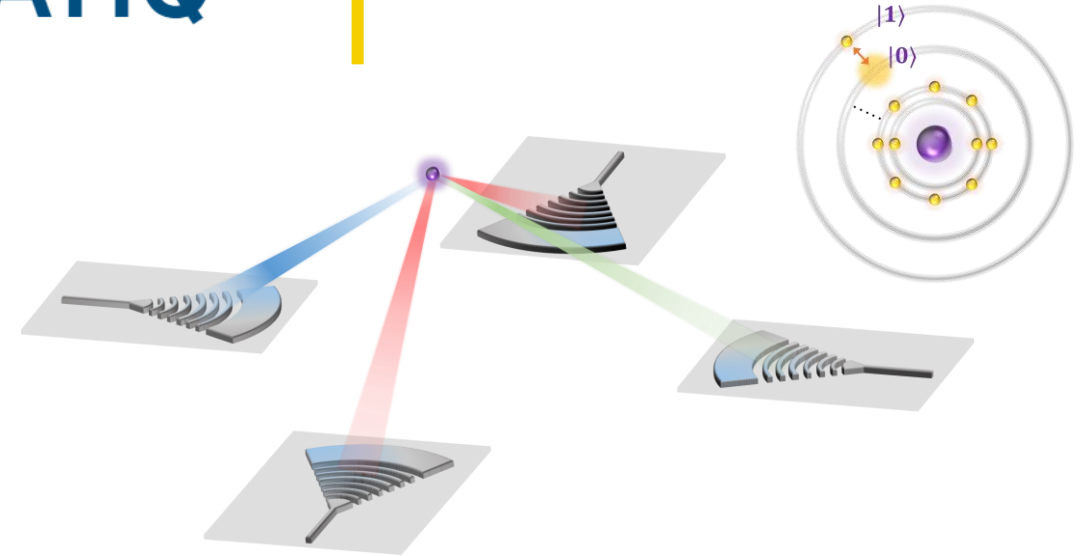
<http://mitchellgroup.icfo.es/mg/pmwiki.php>



<https://www.physics.ox.ac.uk/research/group/ion-trap-quantum-computing>

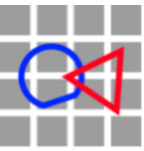


<https://www.bosch-presse.de/pressportal/de/en/robert-bosch-venture-capital-invests-in-quantum-computing-startup-ionq-202304.html>



Establishing AlN WG platform

- High gate fidelity
- Long coherence
- Scalability
- Portable chip



Trapped Ion Qubits Quantum Computer

Project
ATIQ

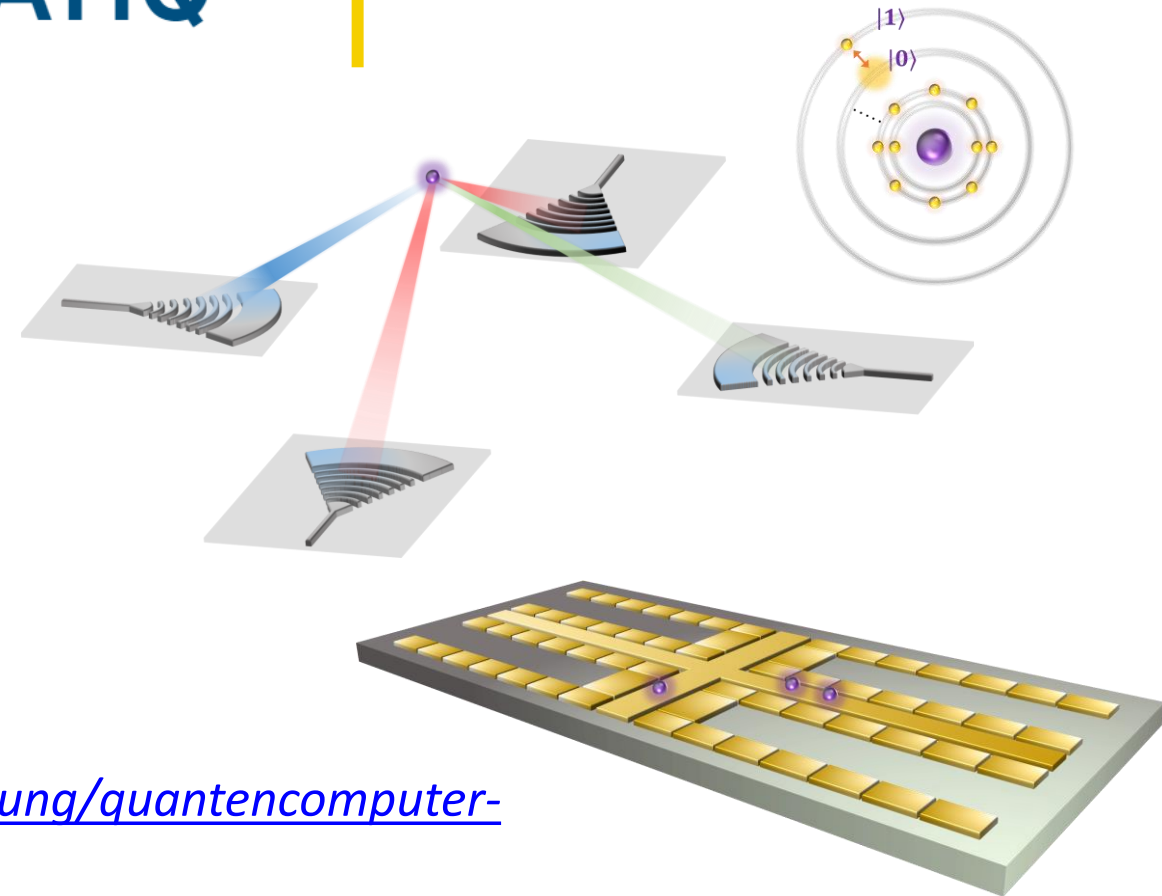


Bundesministerium
für Bildung
und Forschung



quanten
technologien

Stay Tuned!!!



More information on:

- 1) <https://www.quantentechnologien.de/forschung/foerderung/quantencomputer-demonstrationsaufbauten/atiq.html>
- 2) <https://www.quantentechnologien.de/index.html>