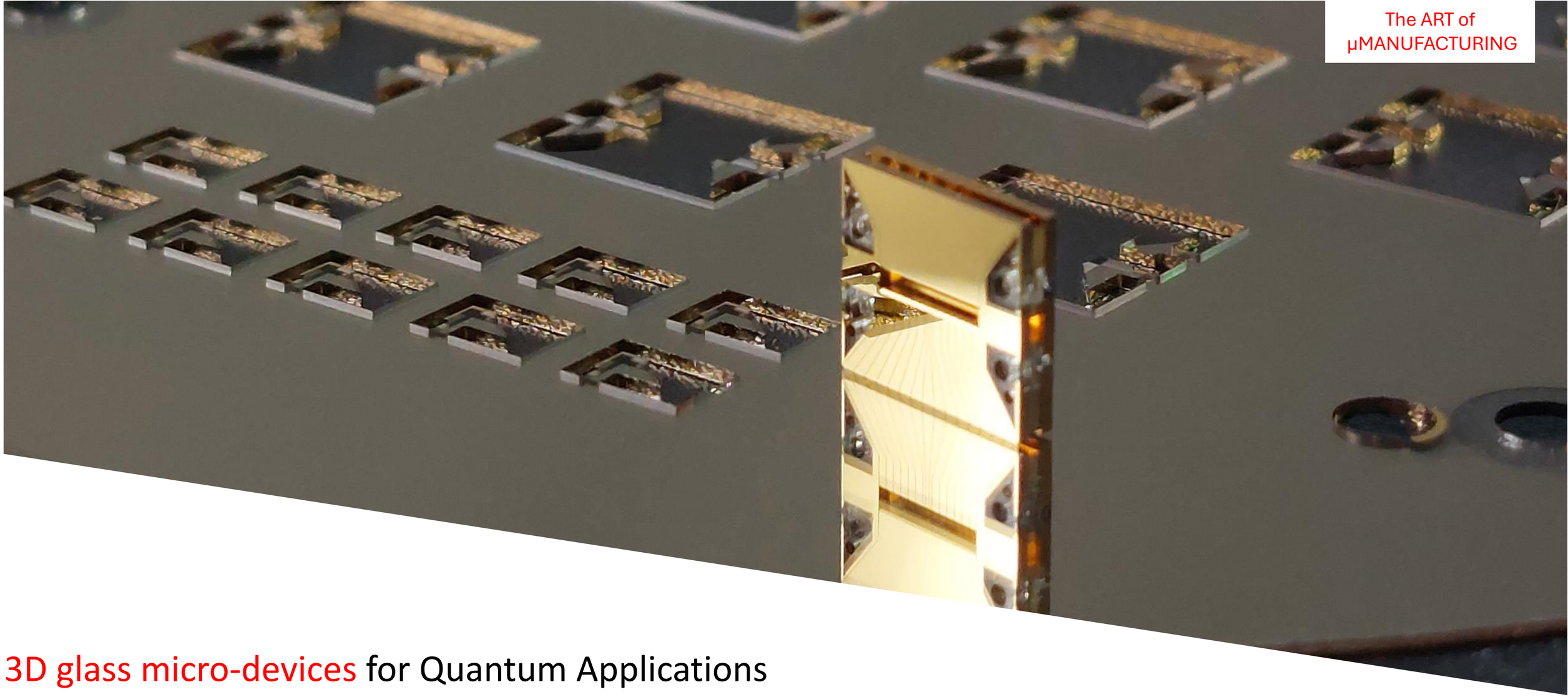
The ART of
µMANUFACTURING



3D glass micro-devices for Quantum Applications

Photonics 4 Quantum, April 7th – 2025

Dr. Cesare Alfieri

SWISS PHOTONICS

QuantumBasel

FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

The Company

FEMTOprint® is your leading global provider of advanced laser processing for glass microdevices.

Swiss made

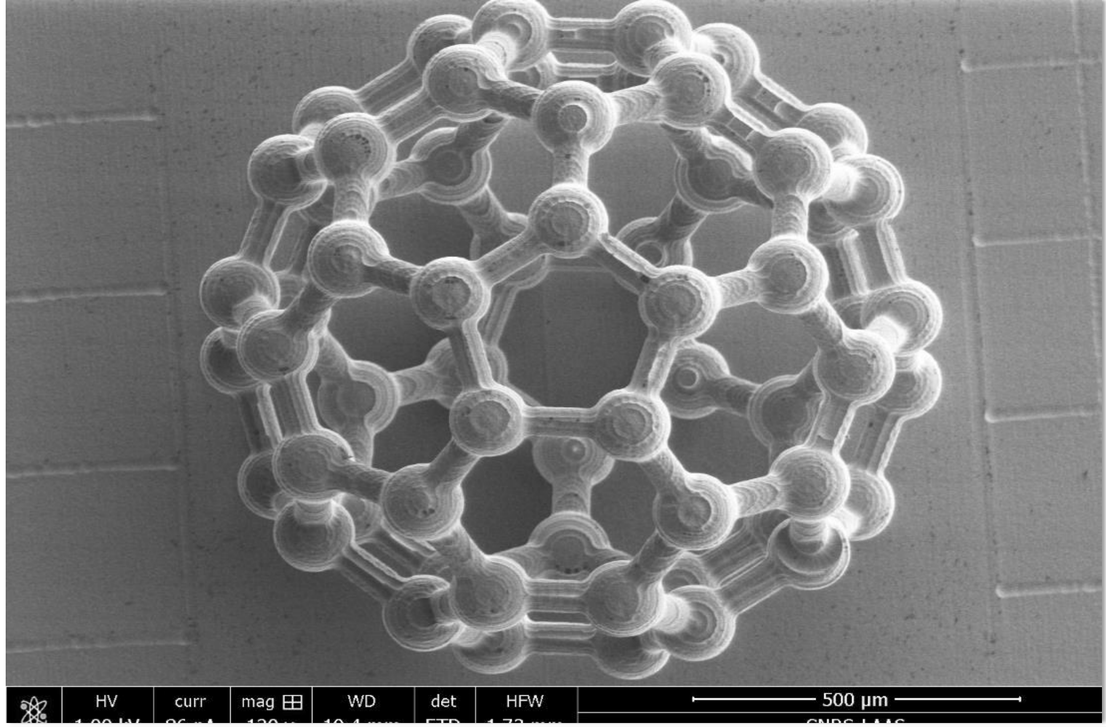
40+ talented professionals

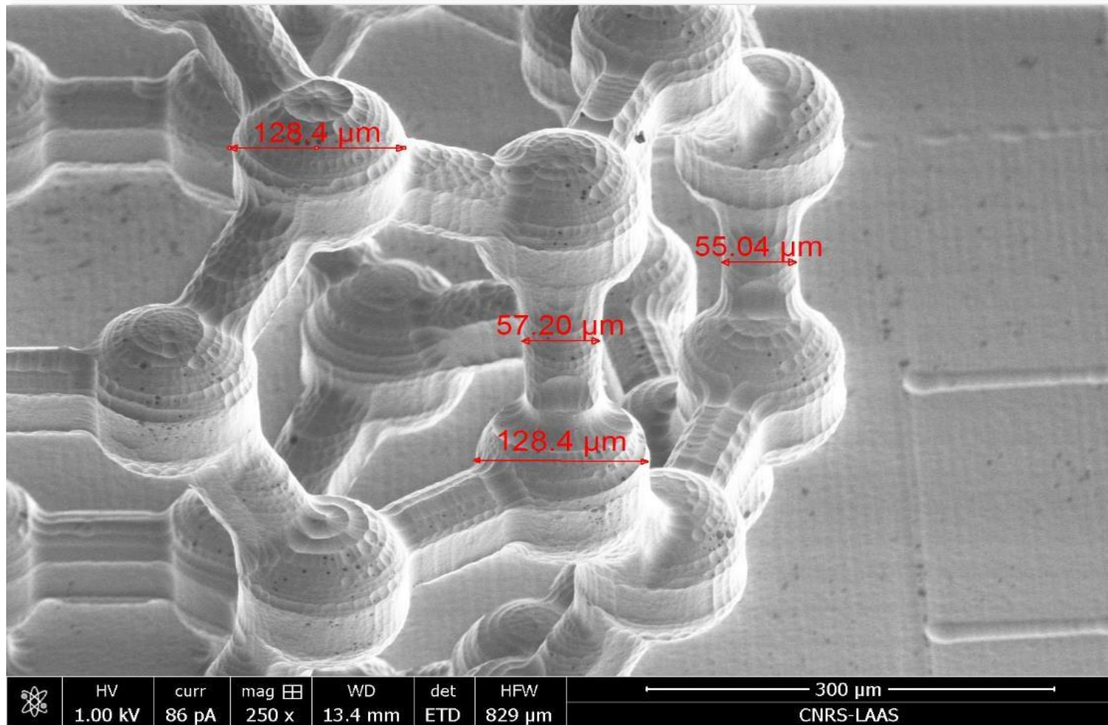
ISO 13485:2016
ISO 9001

Switzerland Sales offices	Agno **HQ & Production**
	Neuchâtel **Representation office**
USA	Ventura, CA **Representation office**
Israel	Distributors
Korea	Distributors

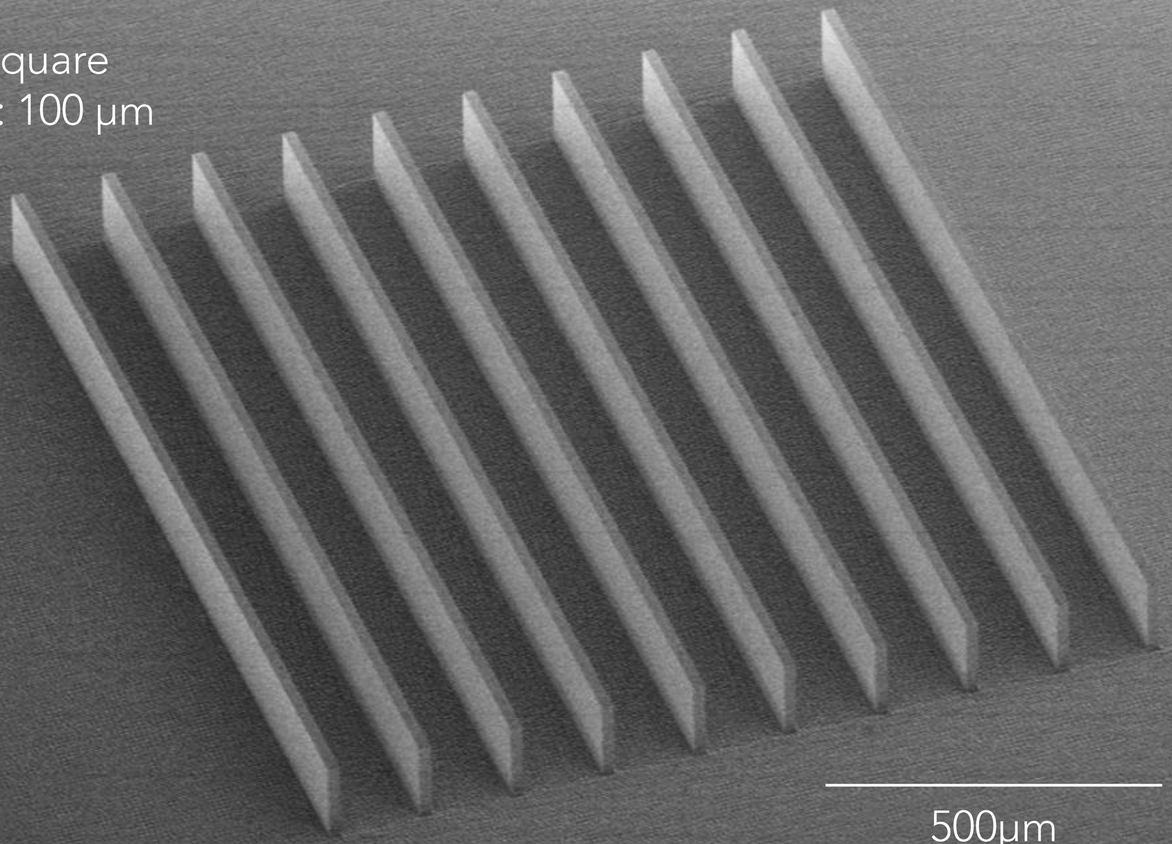
Performances in SiO_2
Resolution and tolerances

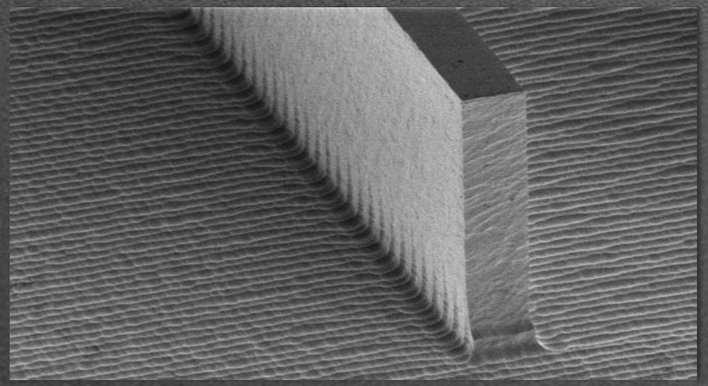
- Process resolution ~ 1 µm
- XY tolerances +/- 1 µm
- Z tolerance +/- 2 µm





1 cm² square
Height: 100 µm



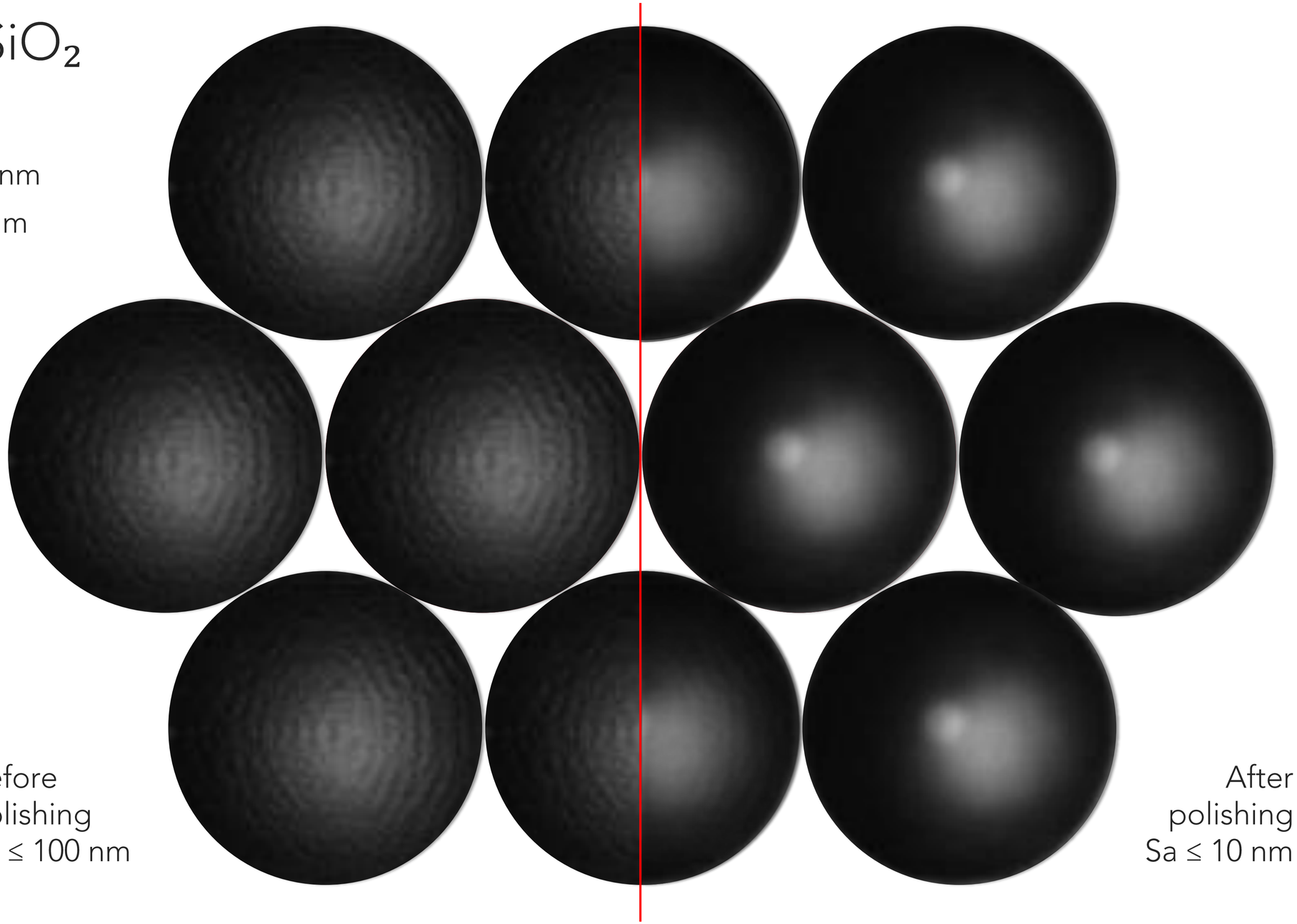


Performances in SiO_2 Aspect ratio

- Aspect ratio ≥ 1:500
- Sidewall deviation ≤ 0.1°
- Bulk height: up to 30 mm
- Working area up to 300 mm Ø

Performances in SiO_2
Surface quality

- Patterned surface Sa ≤ 100 nm
- Surface treatment Sa ≤ 10 nm

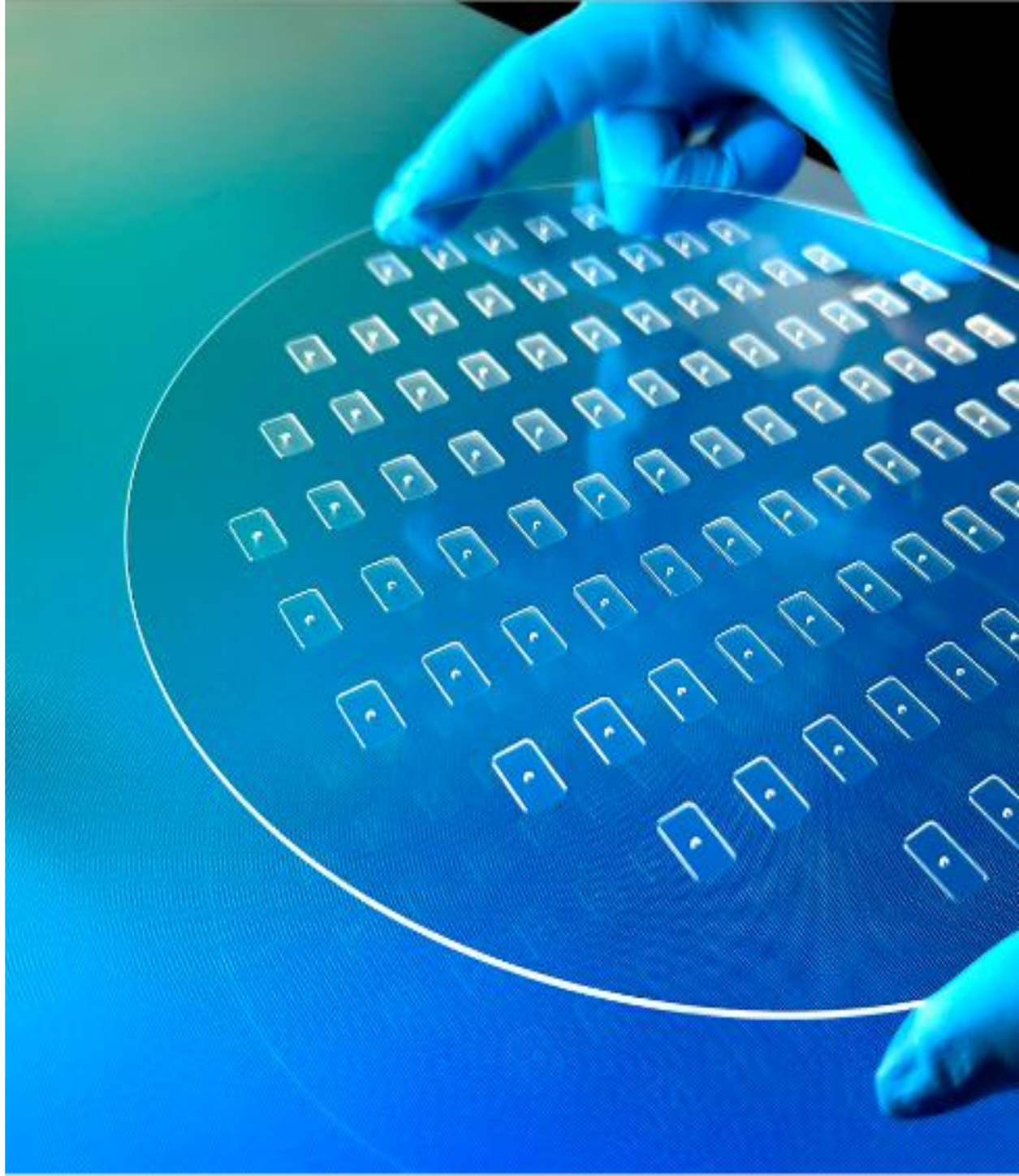


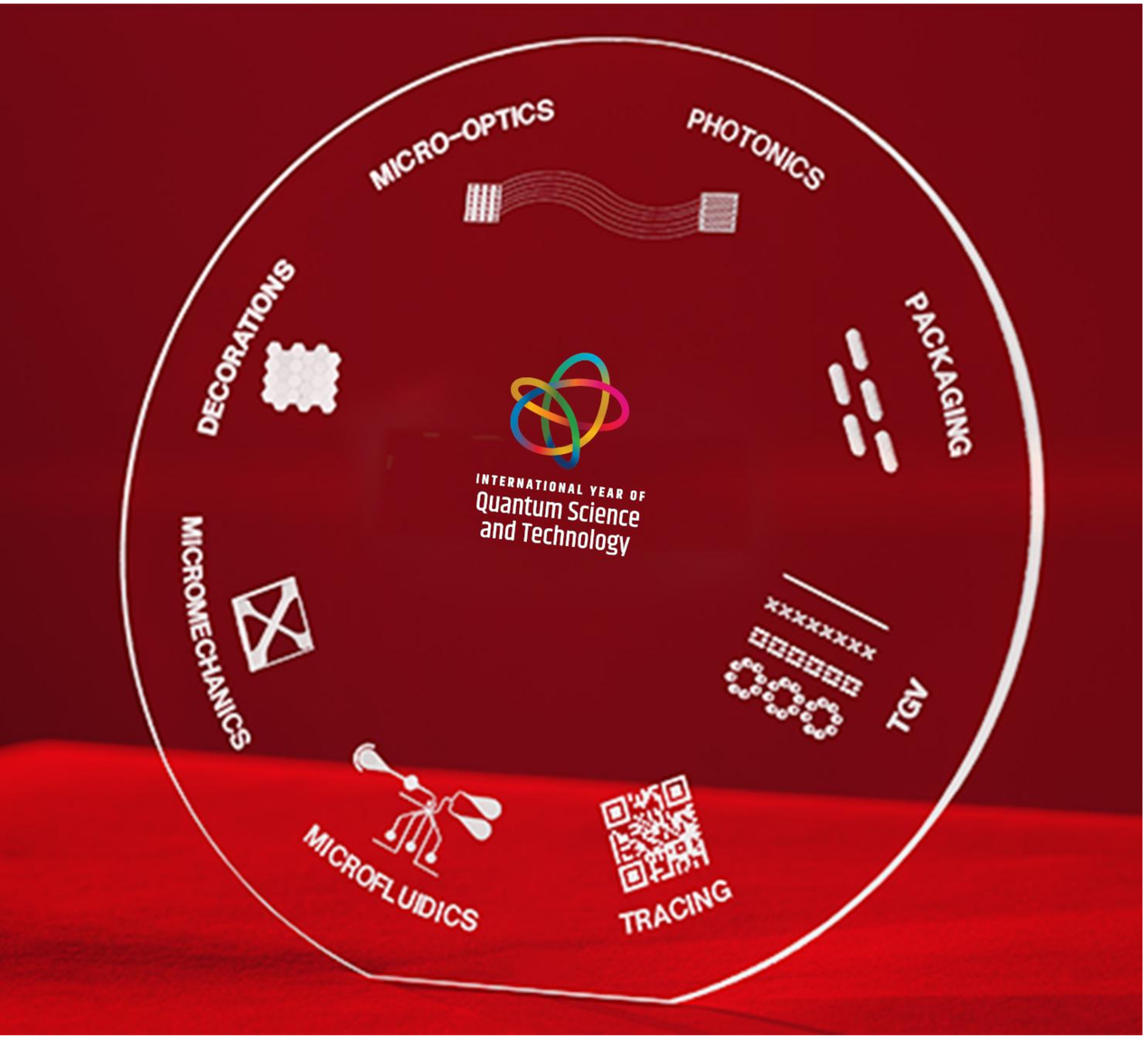
Before polishing
Sa ≤ 100 nm

After polishing
Sa ≤ 10 nm

Wafer-level fabrication

- **Unique** industrial laser processing, compatible with MEMS foundry protocols
- **High-throughput:** capacity for several thousand wafers/product/year
- **Scalability** can be easily enhanced due to proprietary, parallelized processes and production systems

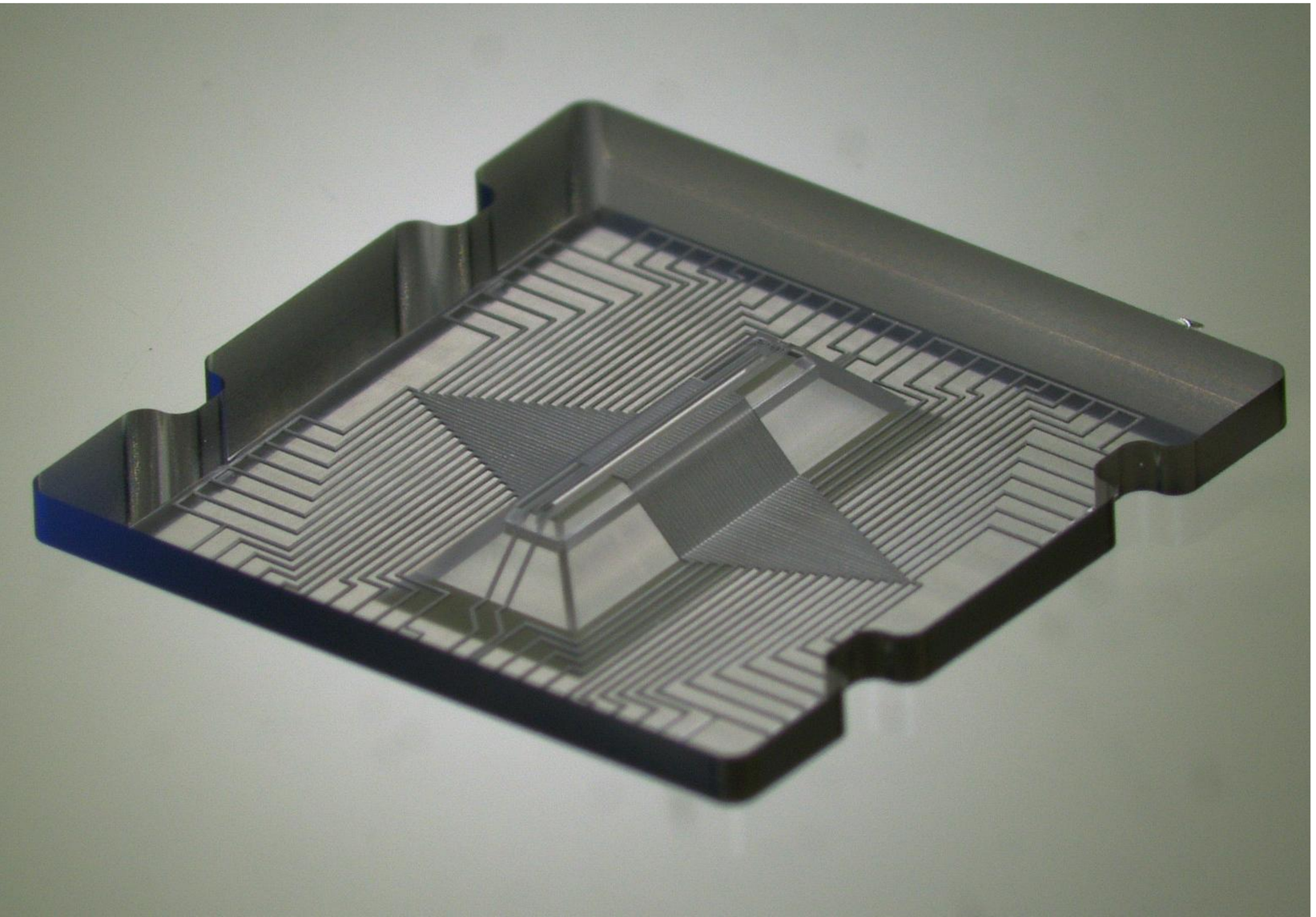




FEMTOprint® 4 Quantum

- Ion Traps
- Glass devices for magnetometry
- Electrical connectivity
- Optical/photonic connectivity

GLASS ION TRAPS a quantum technology



Glass benefits

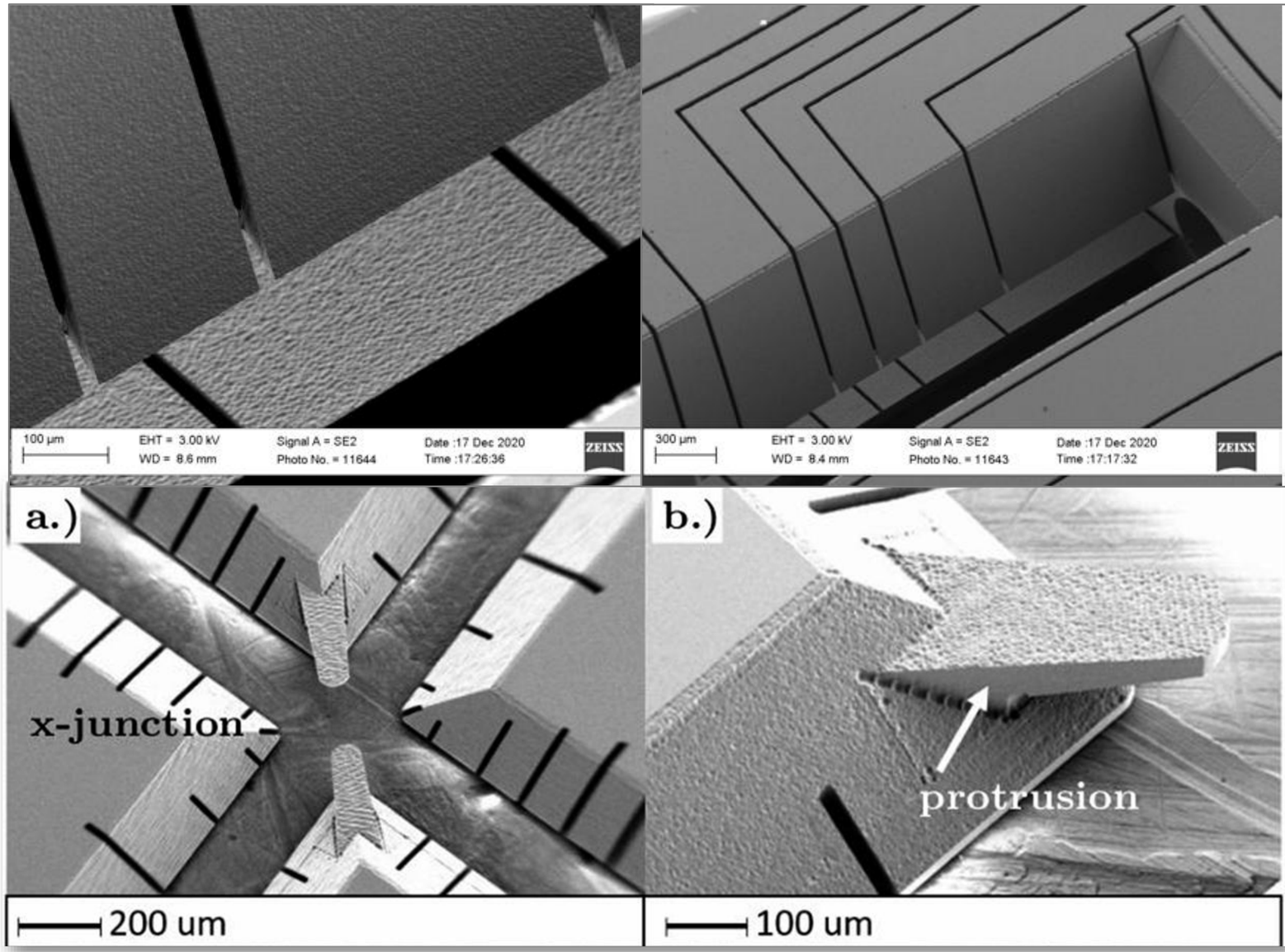
- Precise machining
- High breakdown threshold
- Excellent dielectric properties
- Electro-magnetic inactive
- Low/adjustable CTE (depending on glass type)

Courtesy of University of Seoul

GLASS ION TRAPS a quantum technology

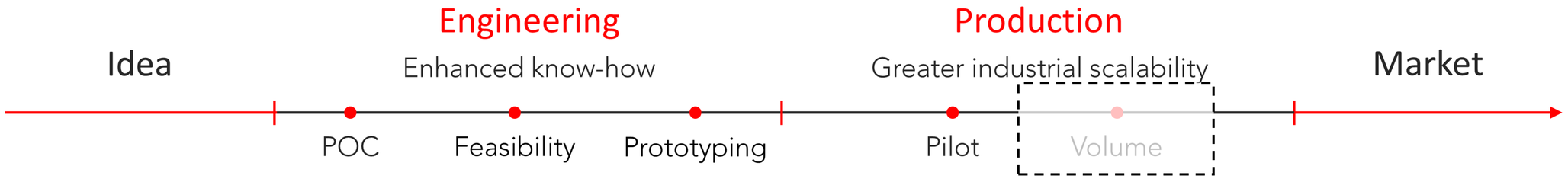
Applications

- Quantum computing
- Quantum simulations
- Optical atomic clocks
- Quantum sensors
- Precision mass spectrometry

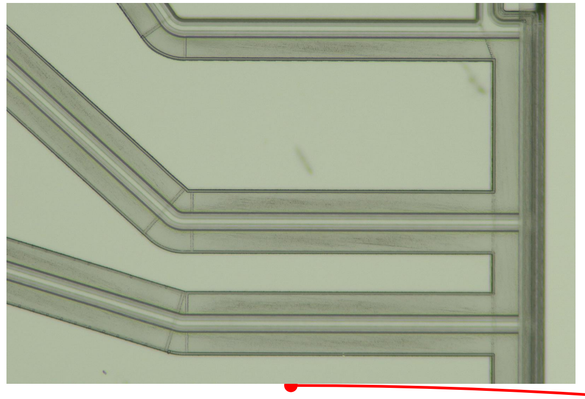


Courtesy of ETHZ

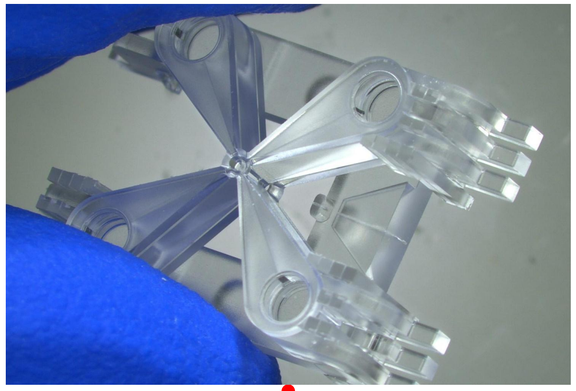
Value proposition



OPTIMIZED TRENCH DESIGN

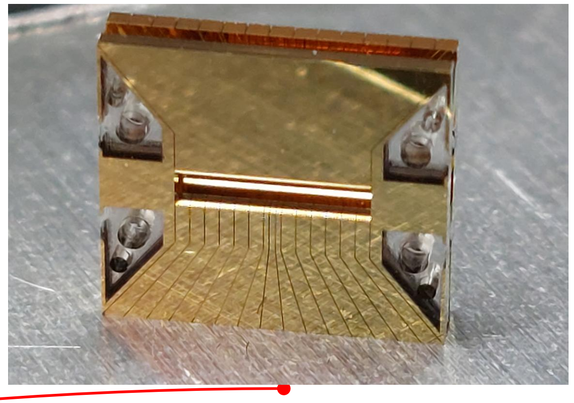


COMPLEX 3D STRUCTURES



Courtesy of OIST

MULTILAYER

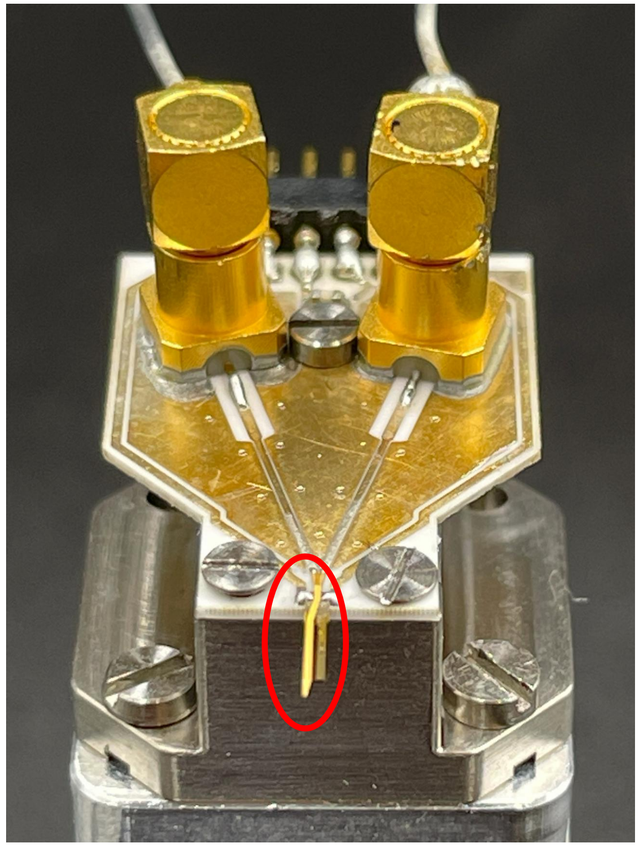


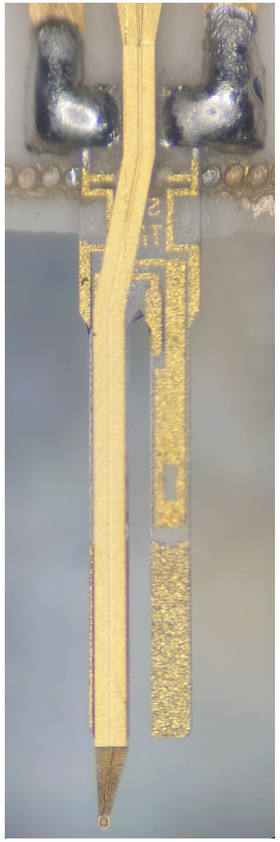
- *< 10µm minimum trench width*
- *Buried structures for better electrode insulation*
- *Overhanging structures and protrusions*
- *Multi-layer structures for higher design flexibility*
- *Trap thickness from < 0.5 mm to > 10 mm*

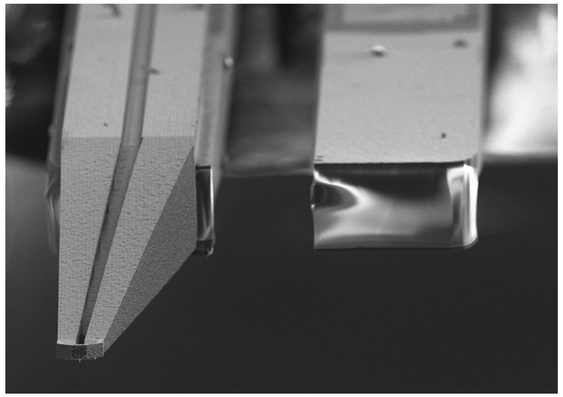
Integrated Microwave Coupling Device for Scanning Nitrogen-Vacancy Magnetometry

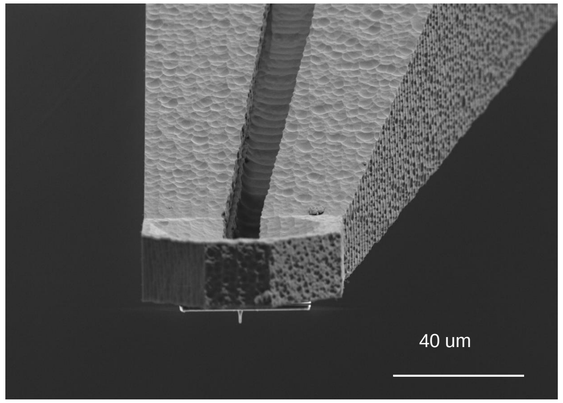
Summary

- Integrated microwave delivery into a scanning probe support structure
- Small and constant distance between microwave drive and sensor
- Simple and reproducible manufacturing
- Ease of use
- Proof of concept scanning NV magnetometry



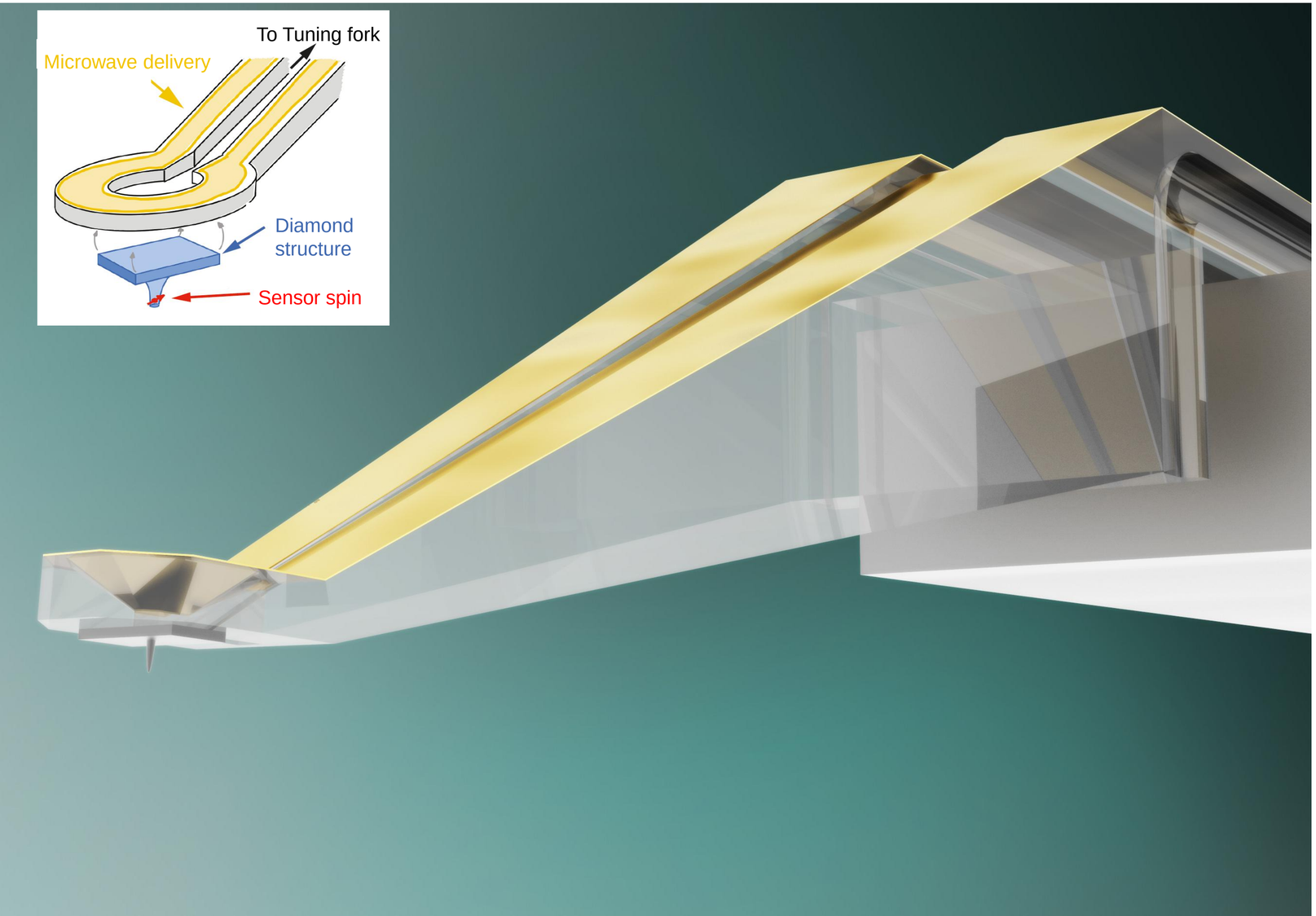






Courtesy of University of Basel

Integrated microwave delivery with glass support structure

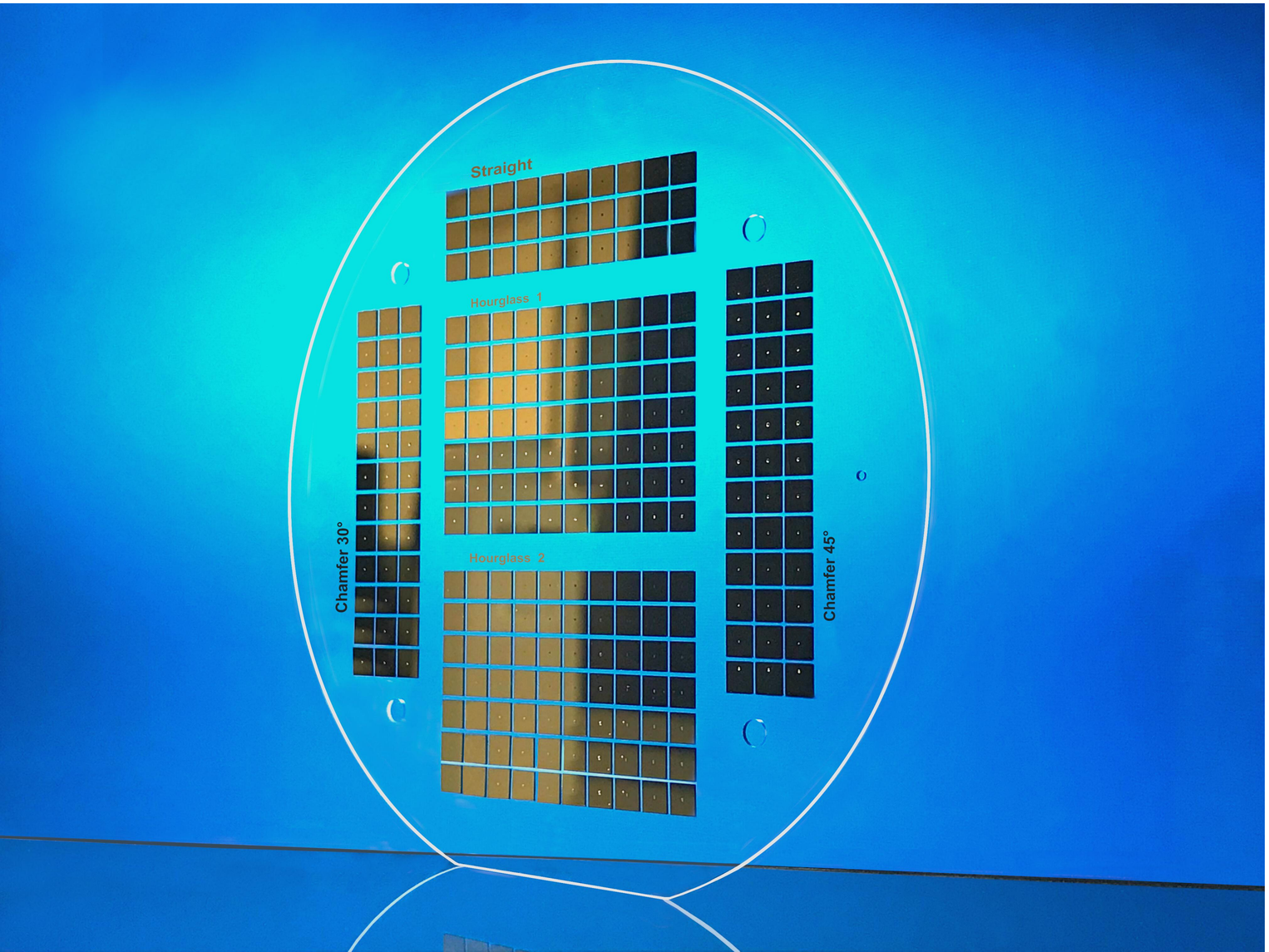


What we can do:

- Monolithic fabrication
- Complex 3D geometries
- Combination of micrometric and millimetric features
- 1 µm tolerances

Courtesy of University of Basel

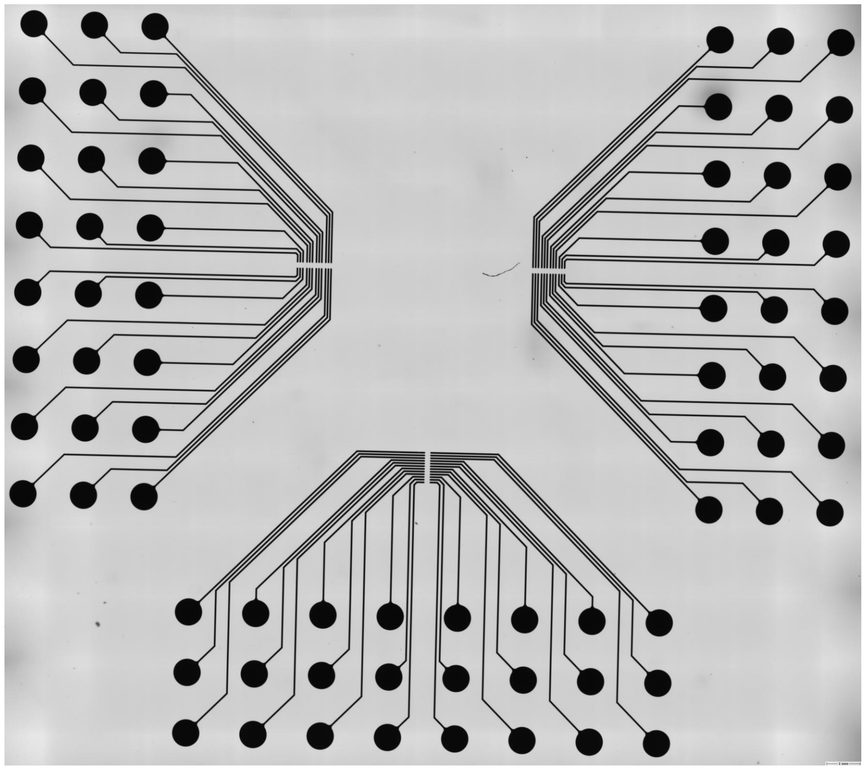
Electrical connectivity for quantum devices

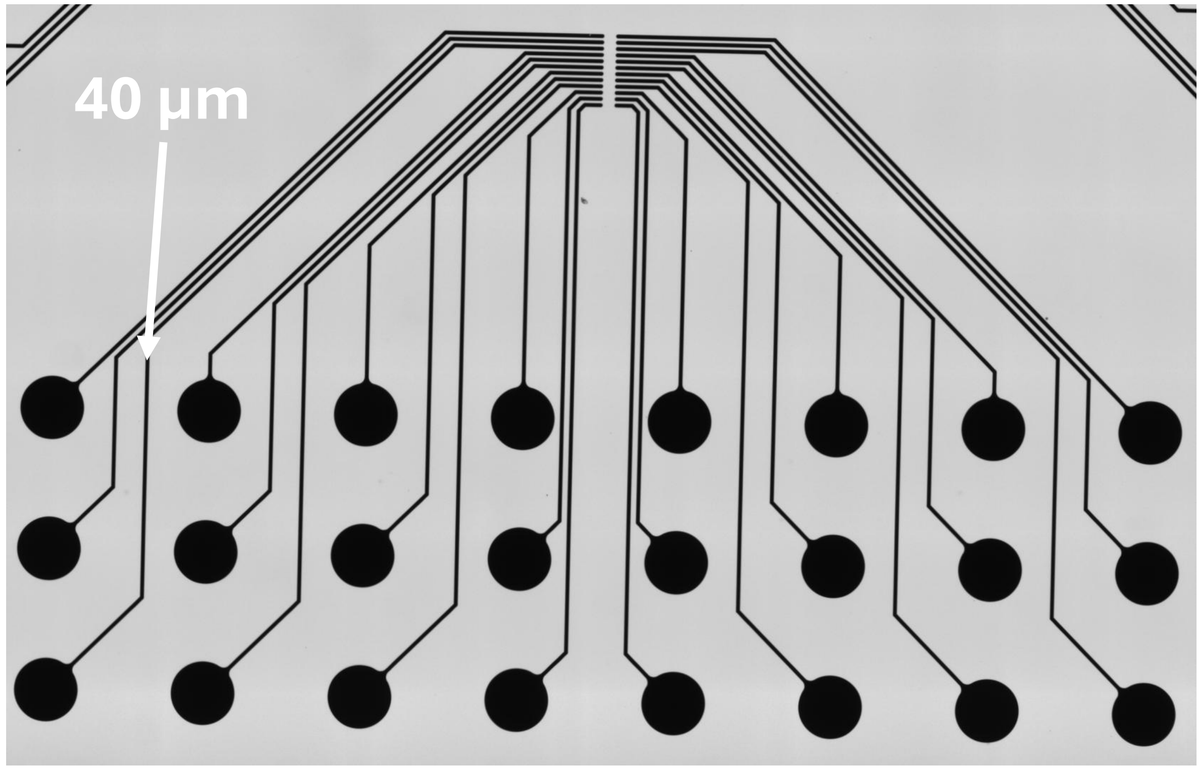


What we can do:

- Deposition of metal films (Ti, Cr, Pt, Au)
- Sputtering or e-beam evaporation
- Deposition at different angles
- Realization of glass hard masks for pads and traces
- Metallization of Through Glass Vias (TGVs)
- Laser ablation of thin films for electrode insulation

Electrical connectivity metal pads and patterned traces

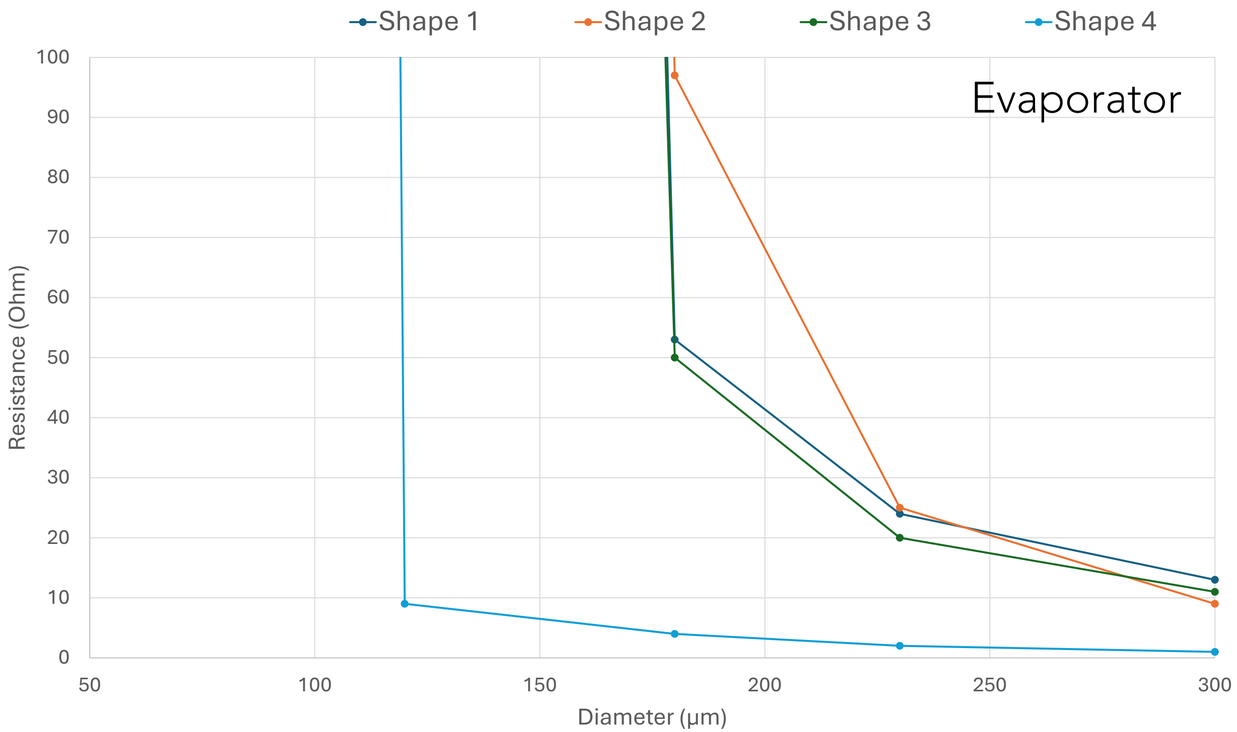


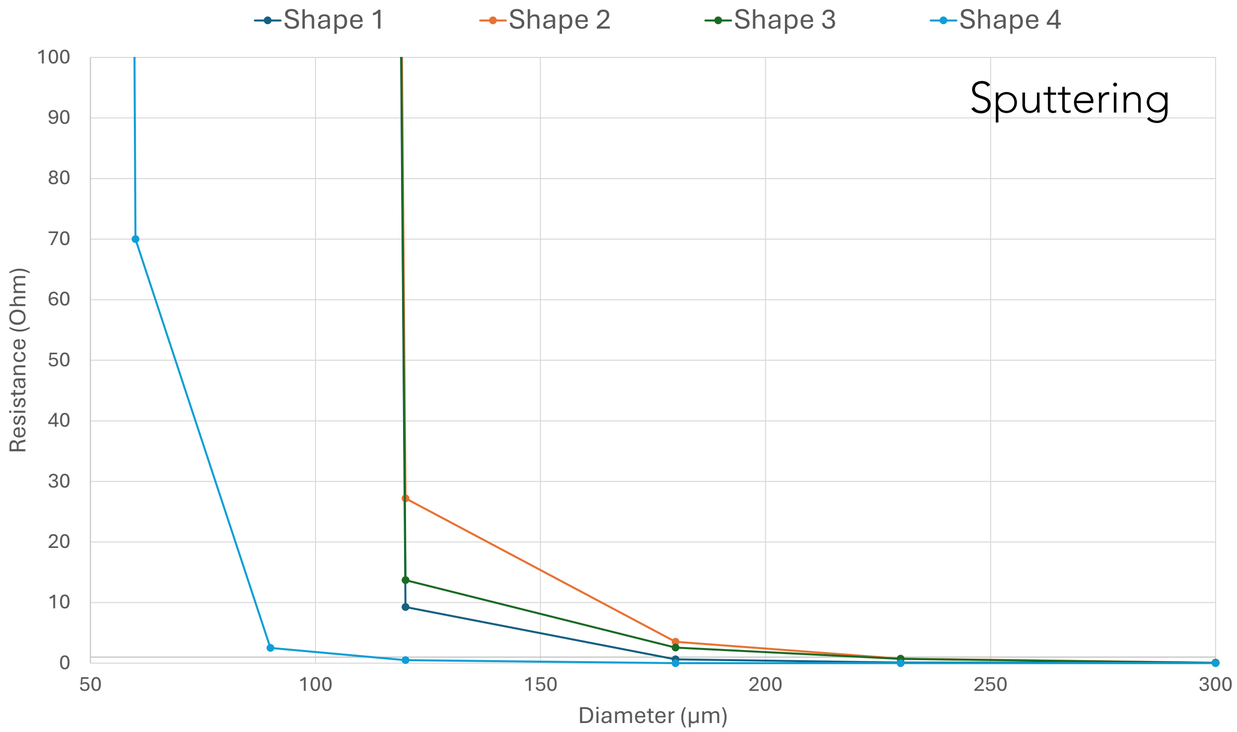


What we can do:

- Production and assembly of glass hard masks to realize metal patterns
- Mask-wafer alignment error < 5 µm
- Minimum trace size/separation < 50 µm

Electrical connectivity Through Glass Vias (TGVs)





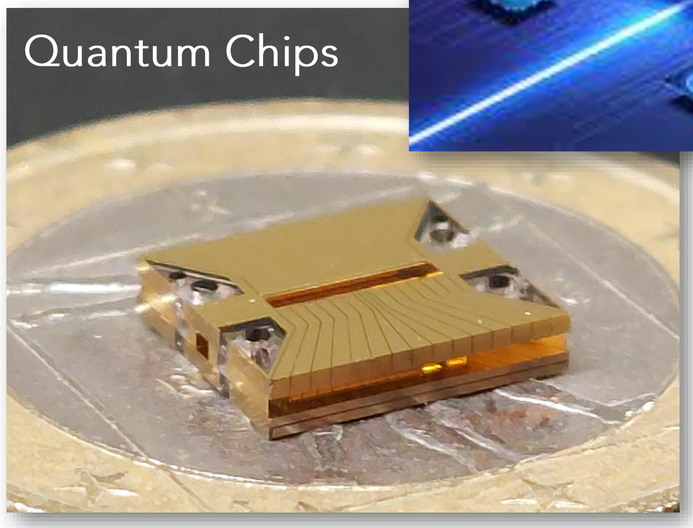
What we can do:

- Different TGV shapes and diameters, adapted to the substrate thickness
- Assure connectivity between TOP and BOT surfaces (R < 1 Ohm)
- Potential fine tuning of resistivity

Photonic connectivity for more integrated quantum devices

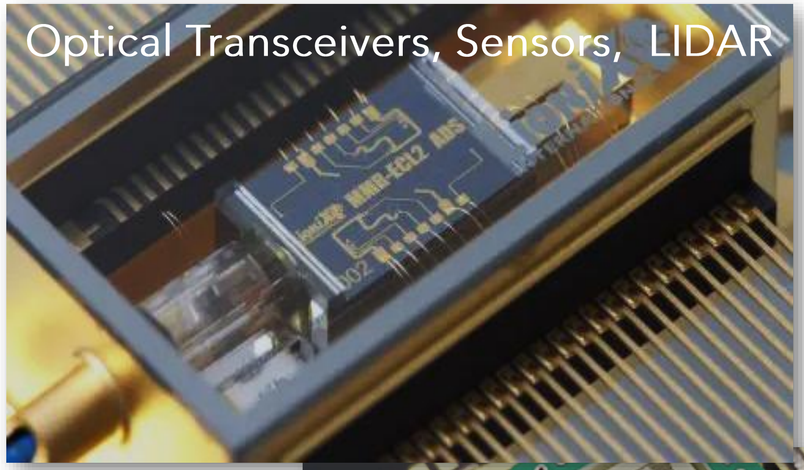
FROM DEVICES …

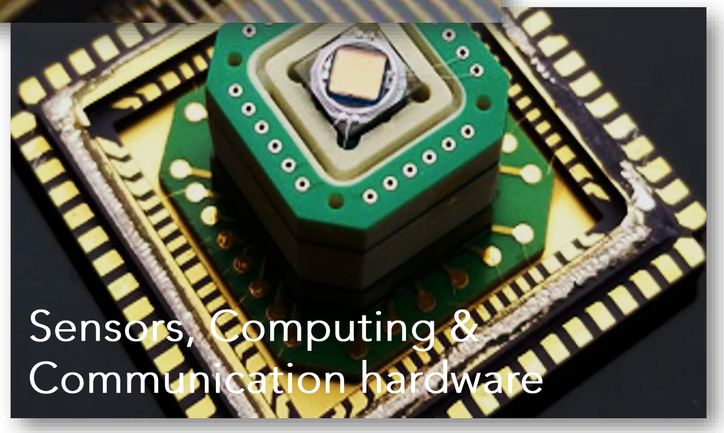
… TO SYSTEMS



PACKAGING

ASSEMBLY





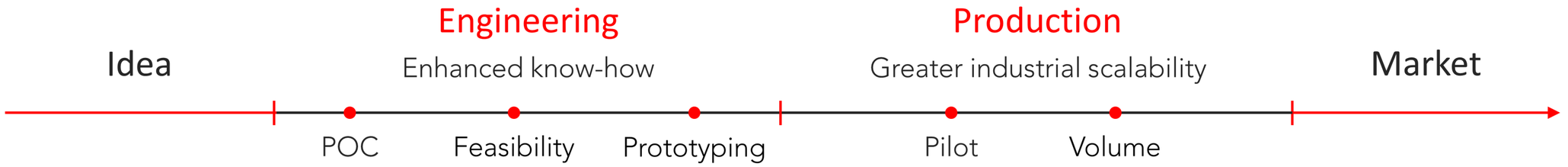
FIBER-TO-CHIP CONNECTIVITY

V-GROOVES
1D & 2D HOLE ARRAYS

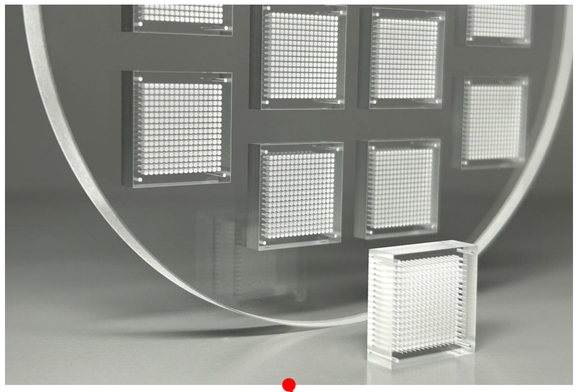
WAVEGUIDES
SSCs, F-IN/-OUT, DCs

MINIATURIZED OPTICS
MICRO-OPTICS

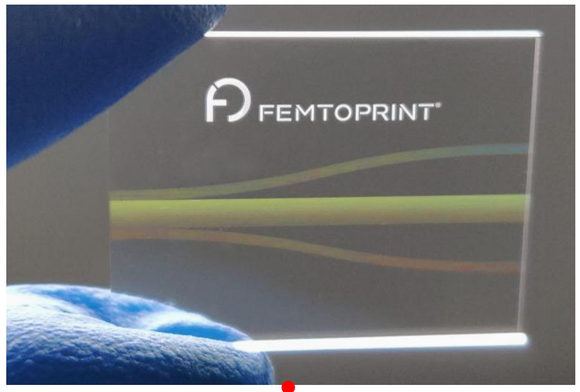
Value proposition



HIGH-PRECISION FIBER ALIGNMENT



BEAM ROUTING



BEAM SHAPING

- *< ± 1µm relative positioning*
- *Monolithic integration of several functionalities*
- *Optical systems for fiber-to-chip connectivity*

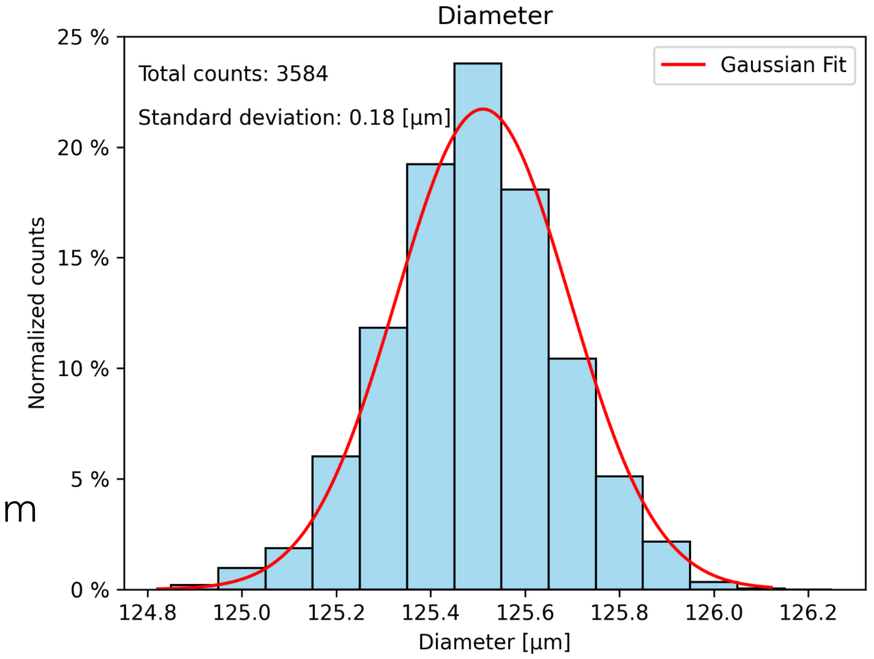
Photonic connectivity high precision fiber ferrules

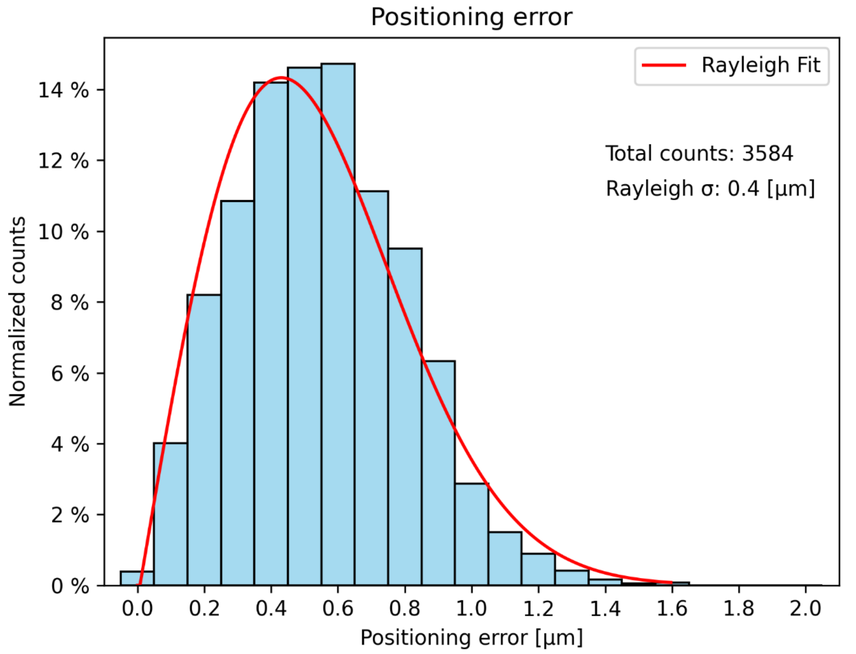
16x16 ARRAY

Fused silica

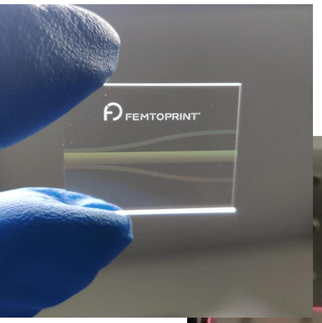
Thickness = 5 mm
Pitch = 0.75 mm
Target diameter = 0.1255 mm

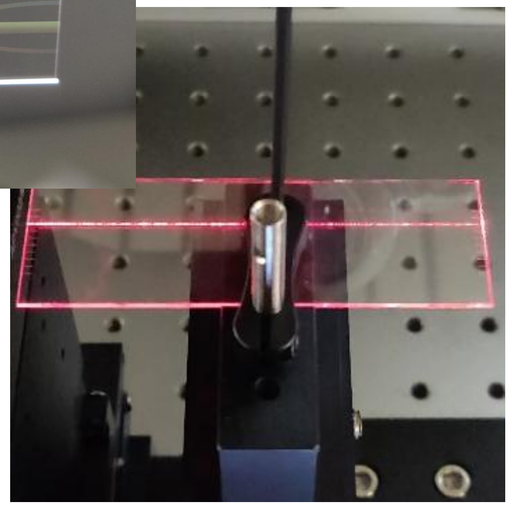
Sub-µm control on hole diameter & position

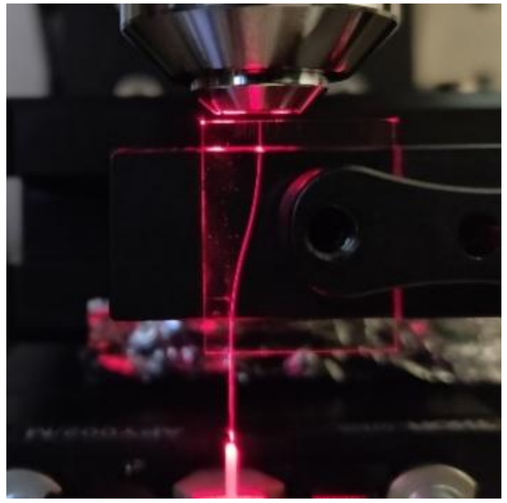




Photonic connectivity 3D waveguides

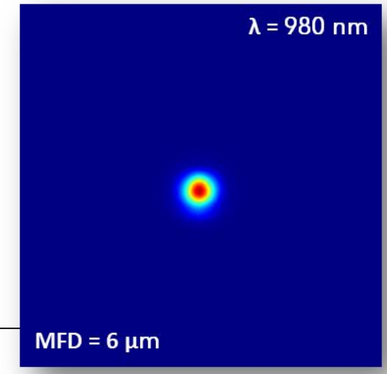


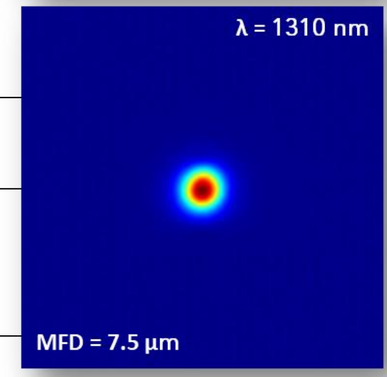


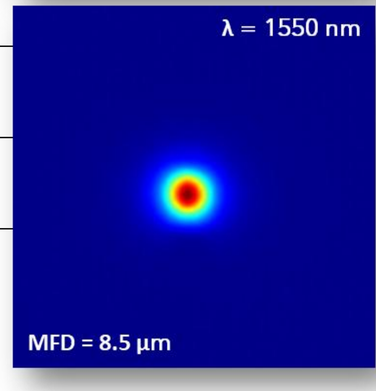


Materials	Fused Silica (FS) Borofloat (BF33) Eagle (EXG)
Machining area	200 x 200 x 3 mm Whatever shape
Wavelength λ [nm]	980, 1310, 1550
MFD for SM [µm]	Tunable between 6 and 12 µm Circularity > 95%
Relative positioning	< ± 1 µm
Min. Bending Radius	≤ 20 mm
Propagation Loss	≤ 0.2 - 0.3 dB/cm
Δn	10^{-2} - 10^{-3}

LIGHT GUIDING



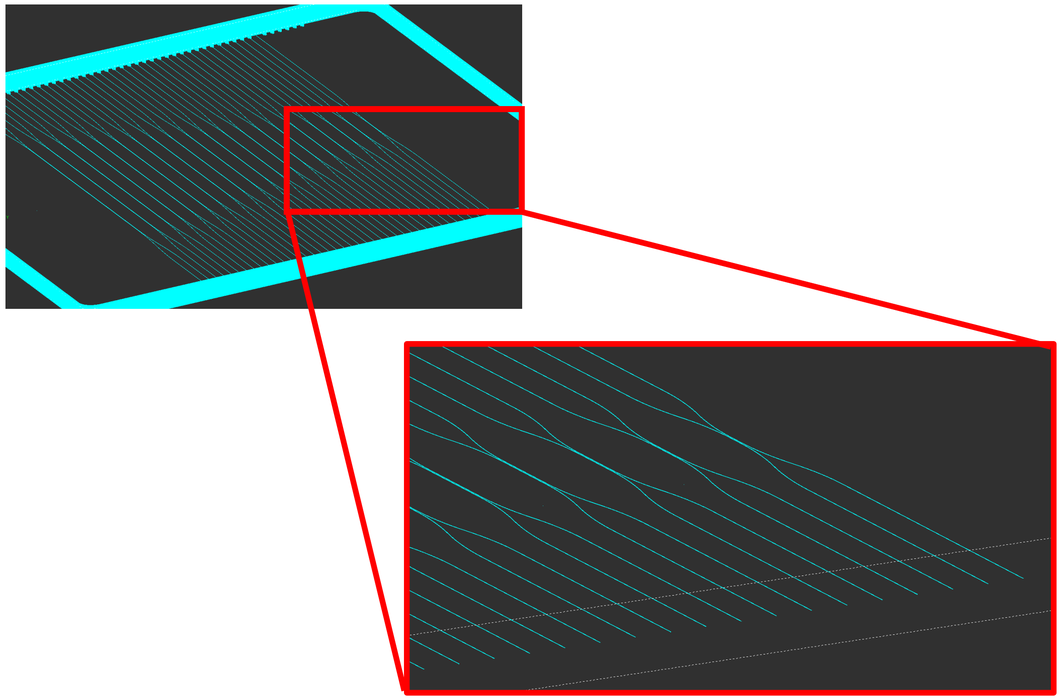


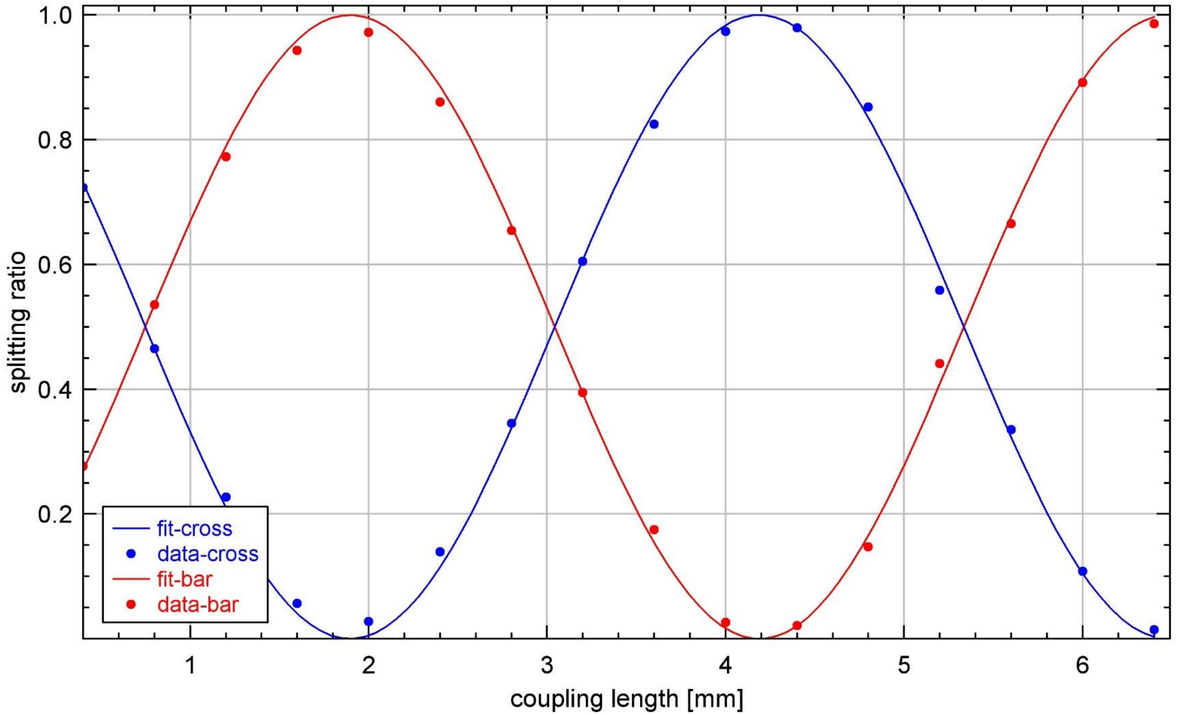


What we can do

- Single mode & Multi-mode waveguides
- 3D waveguides with bending in XYZ
- In-bulk termination and tapering
- Alignment markers for assembly & packaging
- Facet polishing for rapid prototyping & characterization

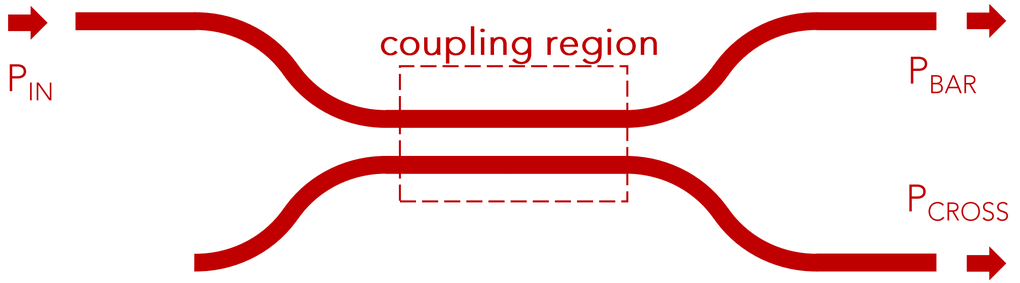
Photonic connectivity directional couplers



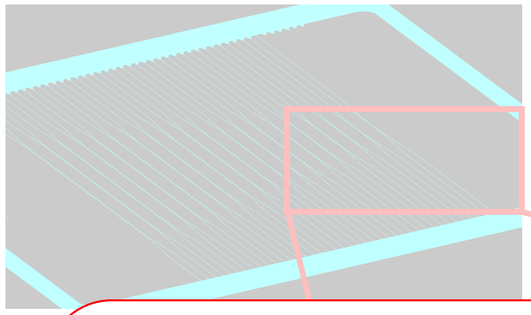


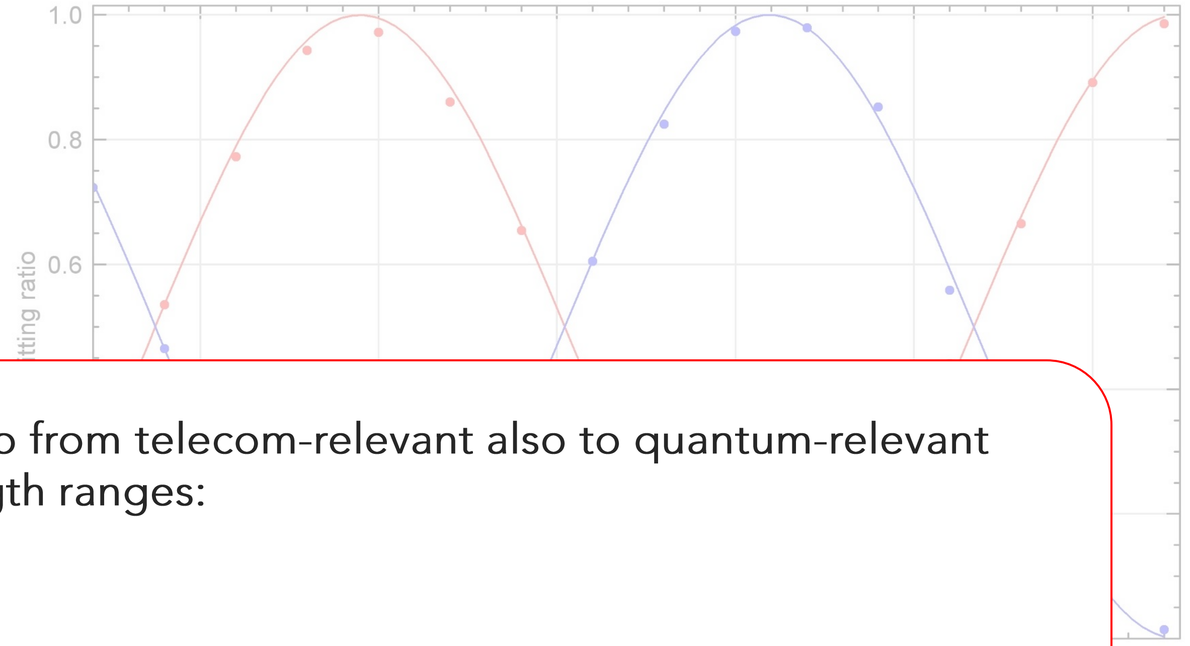
1310nm

- Output channel pitch : 250 µm
- Full power transfer at approx. 2.3 mm
- Total Loss for 50/50 splitting approx. 1.6dB



Photonic connectivity directional couplers



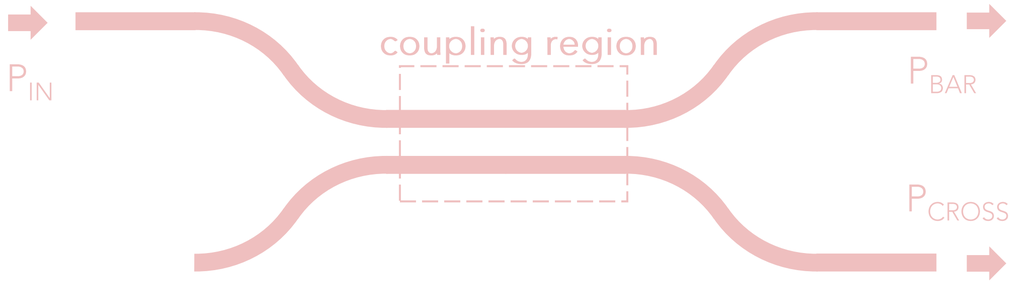


Work in progress to extend our spectral portfolio from telecom-relevant also to quantum-relevant wavelength ranges:

- 1760 nm (Barium)
- NIR (700-800 nm)
- Visible (400-500 nm)

1310nm

- Output channel pitch : 250 µm
- Full power transfer at approx. 2.3 mm
- Total Loss for 50/50 splitting approx. 1.6dB



Photonic connectivity Micro-Optics

What we can do:

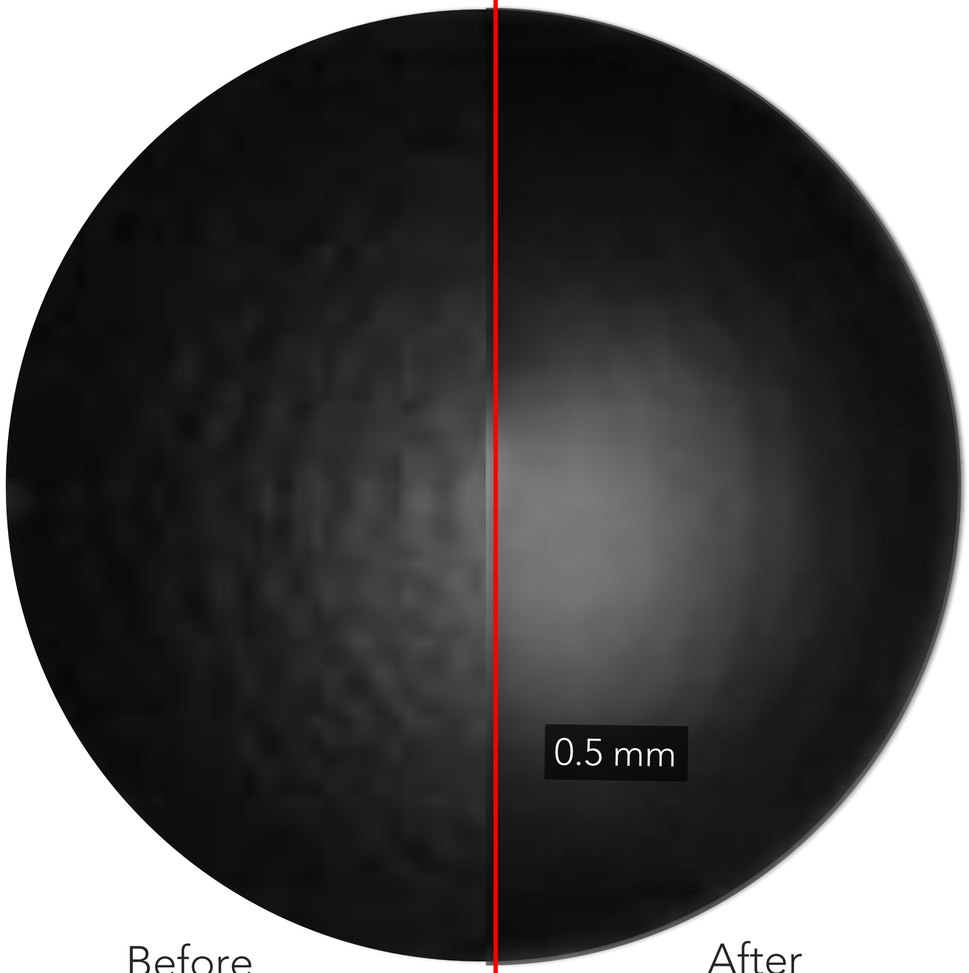
- Refractive optical elements
- Curved lenses and mirrors
- Freeform optics
- SAG down to <10 µm
- Shape deviation typ. < 1.5 µm
- Multiple optical elements can be fabricated in a single production step for best alignment

Shallow Micro-Lens Array

Beam Shaping

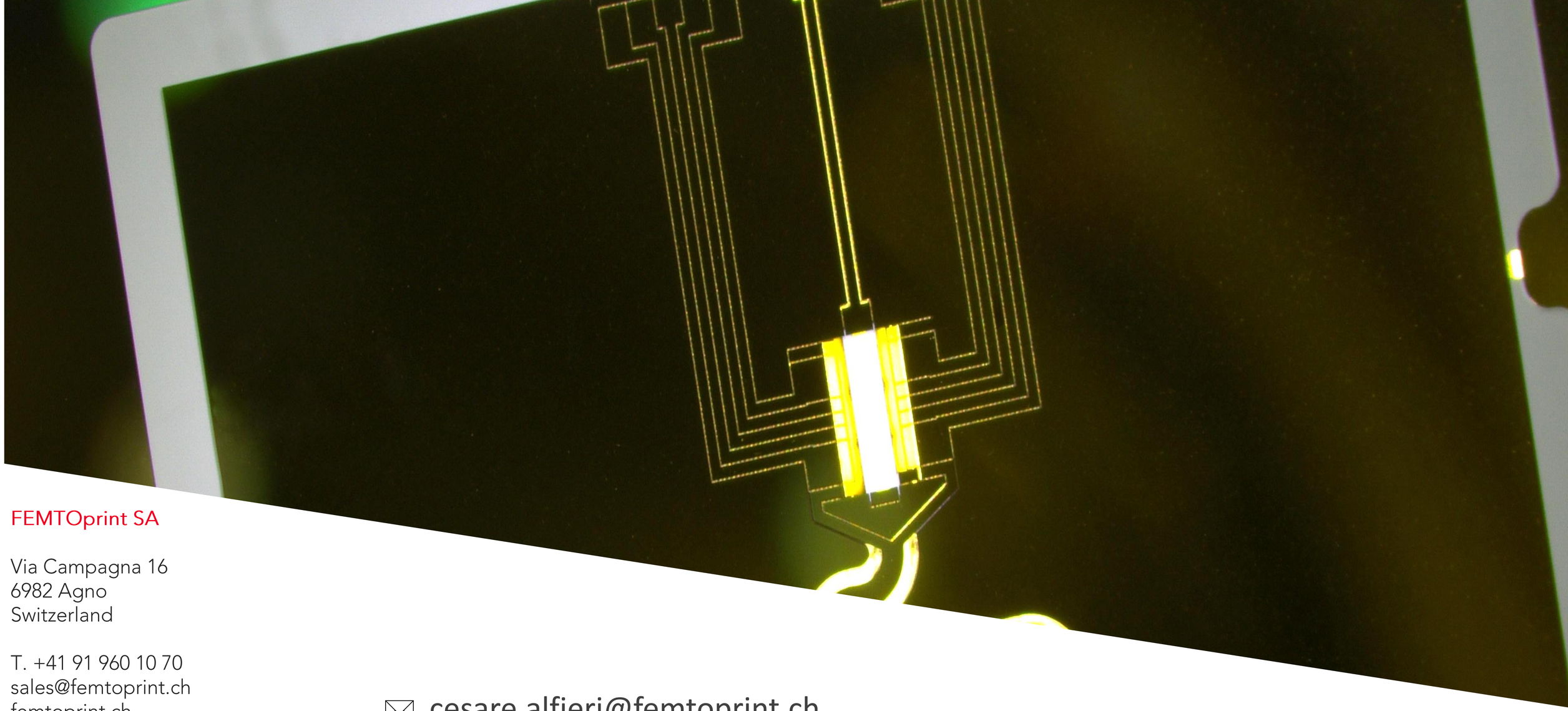
Hexagonal closely packed MLA
100x spherical micro-lenses

- Diameter = 500 µm
- RoC = 650 µm
- SAG = 50 µm



Micro-machined MLAs
in Fused Silica

- RoC = 625 ± 5.0 µm
- SAG = 51.1 ± 1.5 µm
- Sa = 4.8 ± 3.3 nm
- Shape accuracy: < 1.5 µm



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