



Design and Manufacturing of Glass Miniaturized Optical Systems for Compact Fiber-to-Chip Connectivity

Swiss Photonics

Photonic processes for multi-scale smart product functionalities

November 8th, 2024

Davide Farina

SWISS PHOTONICS

FEMTOPRINT
3D PRINTING FOR GLASS MICRODEVICES

01



FEMTOprint is a Swiss high-tech
Contract Development and Manufacturing Organization (CDMO)
specialized in
high-precision 3D laser microfabrication in glass



FOUNDED IN
2013



40+ TEAM
MEMBERS



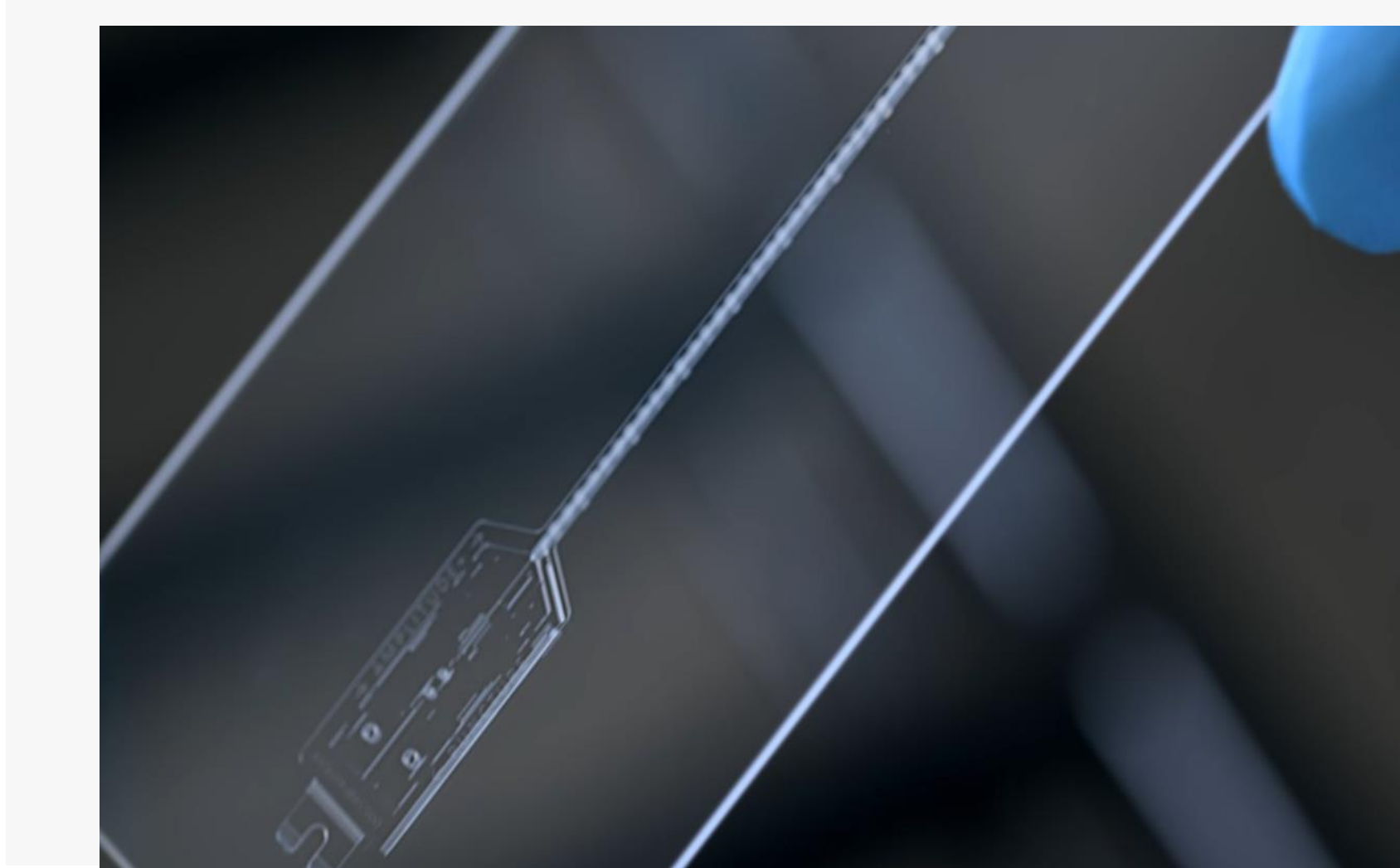
EXPORT TO
30+ COUNTRIES



ISO 13485:2016
ISO 9001:2015



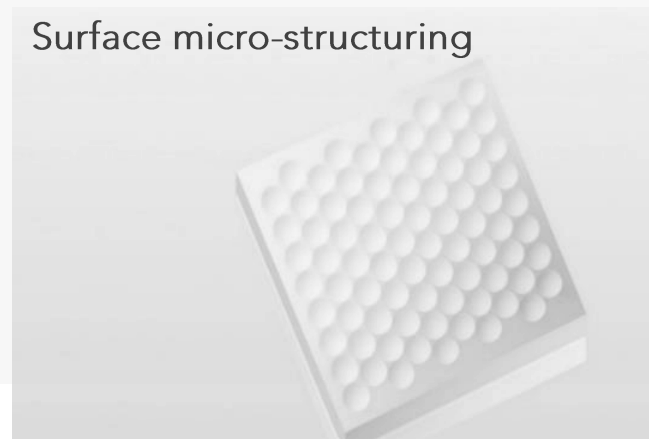
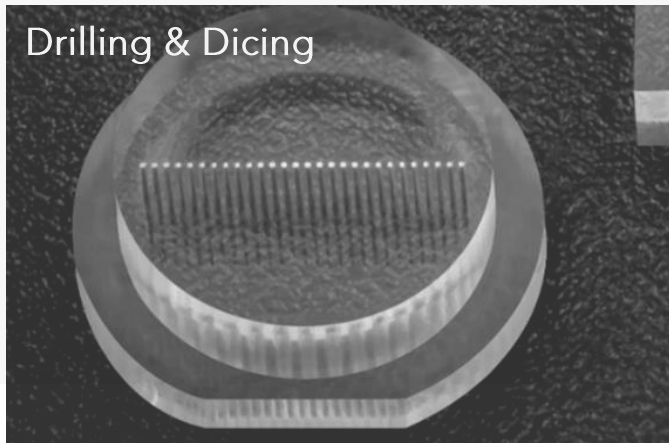
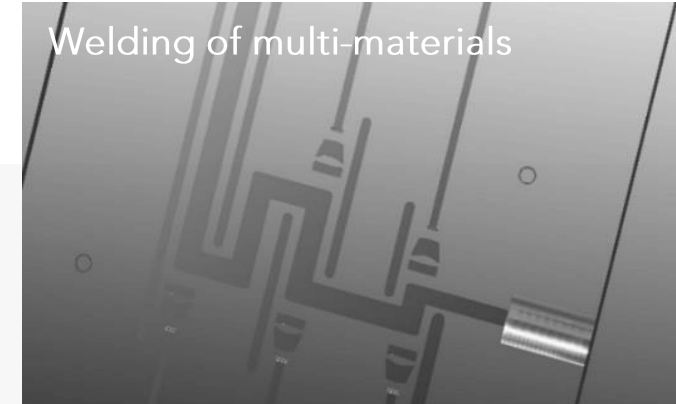
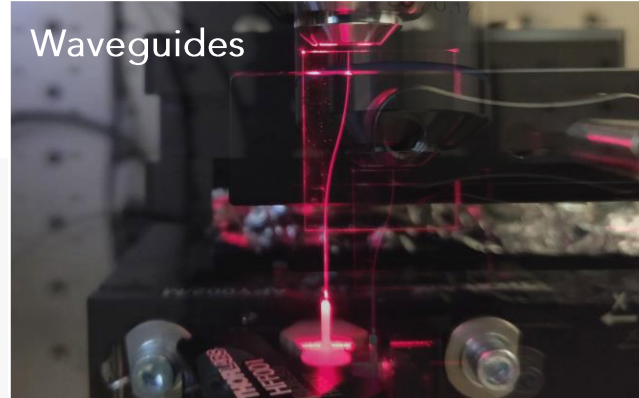
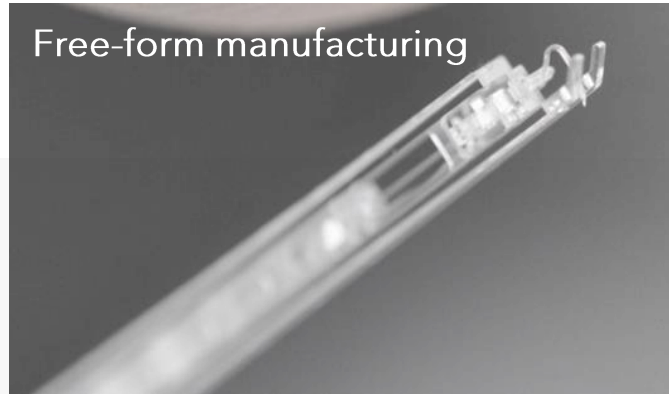
02



GLASS FAMILIES

- Fused silica (SiO_2)
- Fused quartz
- Borosilicate
- ULE® (Ultra-Low Expansion)
- Aluminosilicate
- Alkali-free
- Other custom materials

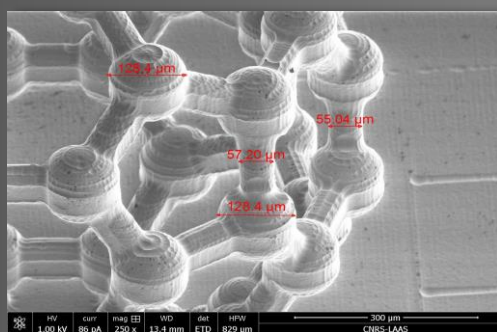
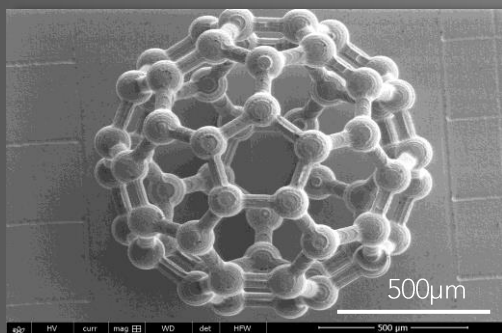
CAPABILITIES



PERFORMANCES

RESOLUTION AND TOLERANCES

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



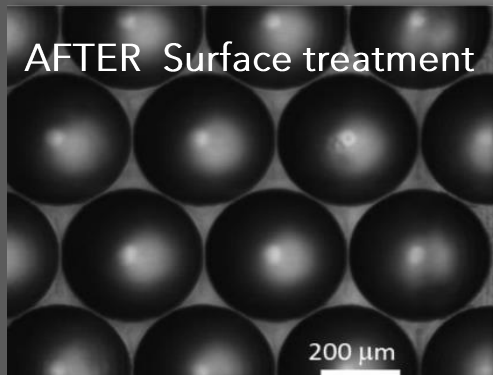
SURFACE QUALITY

- Patterned surface $S_a \leq 100 \text{ nm}$
- Surface treatment $S_a \leq 10 \text{ nm}$

BEFORE Surface treatment

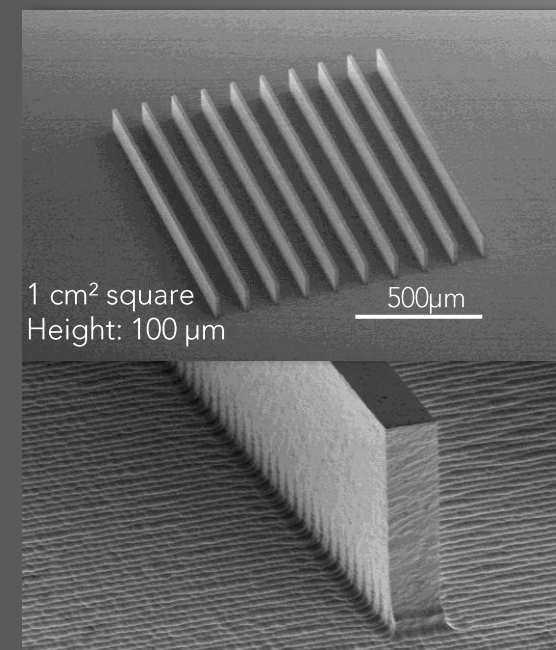


AFTER Surface treatment



ASPECT RATIO

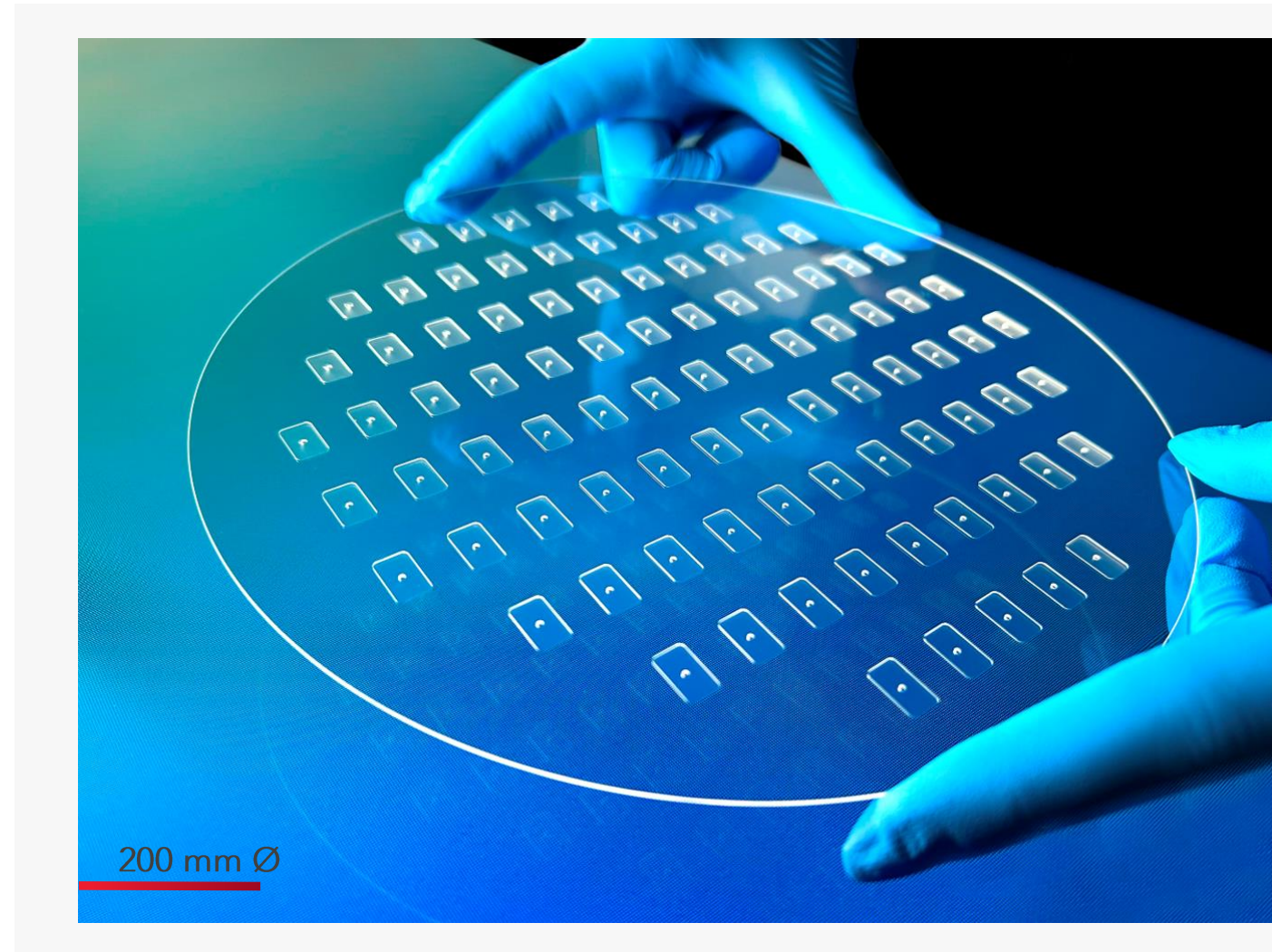
- Hole aspect ratio > 1:500
- Substrate thickness up to 30 mm
- Min. hole diameter < 5 μm \varnothing
- Sidewall deviation < 0.1°
- Sidewall roughness $S_a < 100 \text{ nm}$



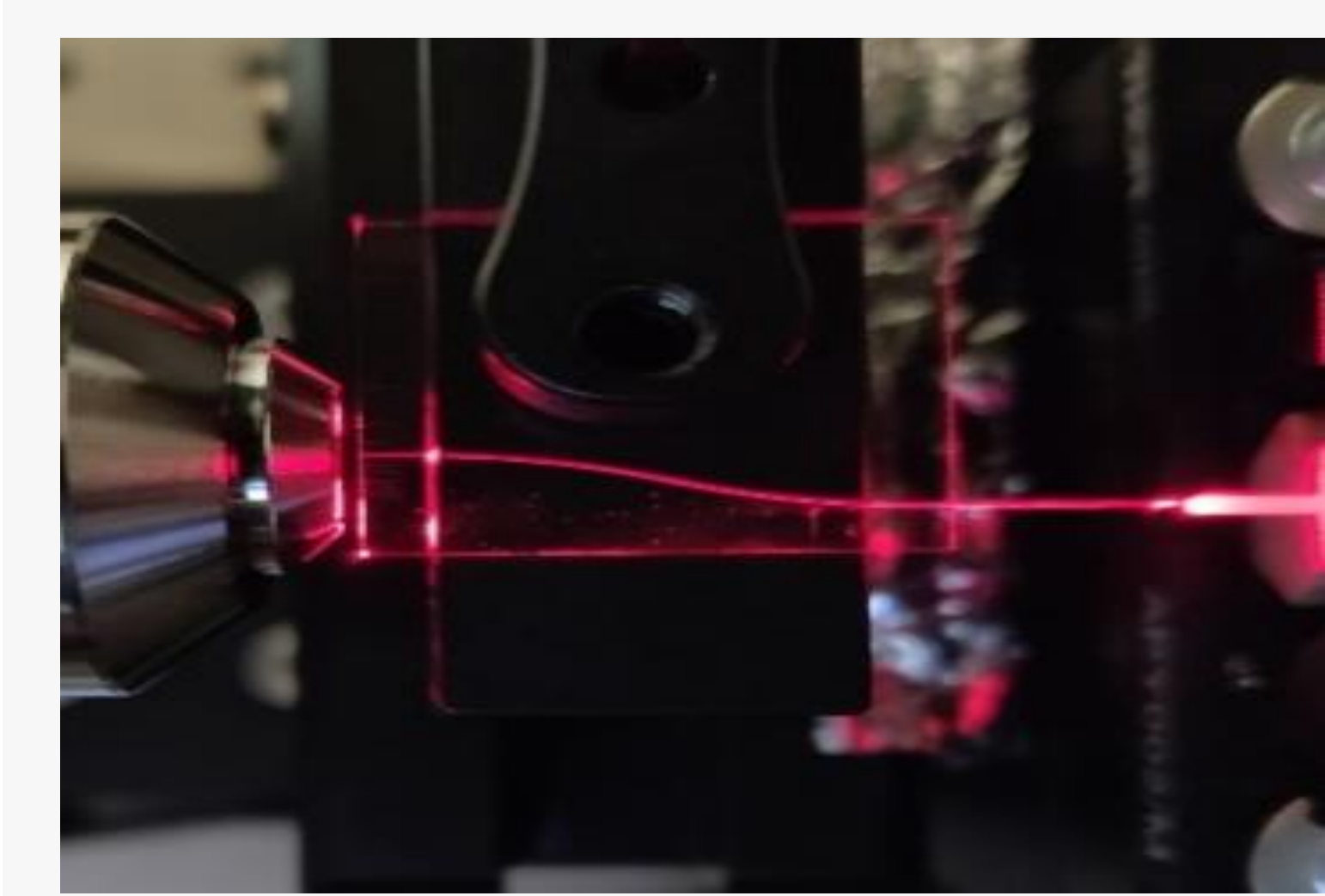
WAFER-SCALE FABRICATION

ADVANTAGES

- **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



03



Fiber-to-chip connectivity for Integrated & Quantum Photonics

FROM DEVICES ...

... TO PRODUCTS

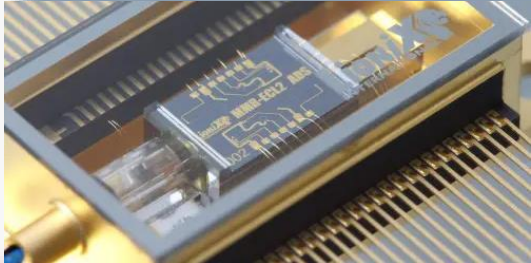
PICs



PACKAGING

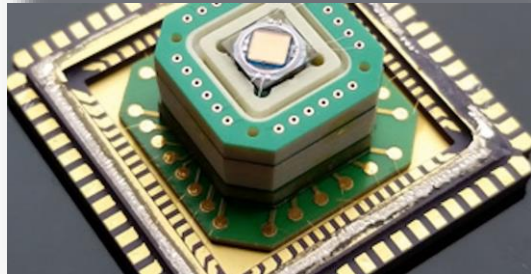
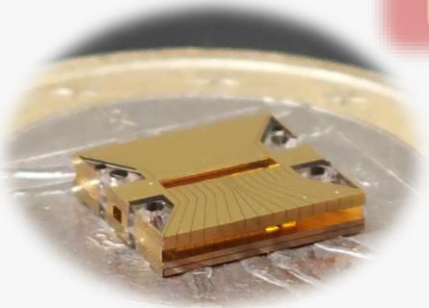


ASSEMBLY



Optical Transceivers, Sensors, LIDAR, etc.

Quantum Chips



Sensors, Computing & Communication hardware, etc.

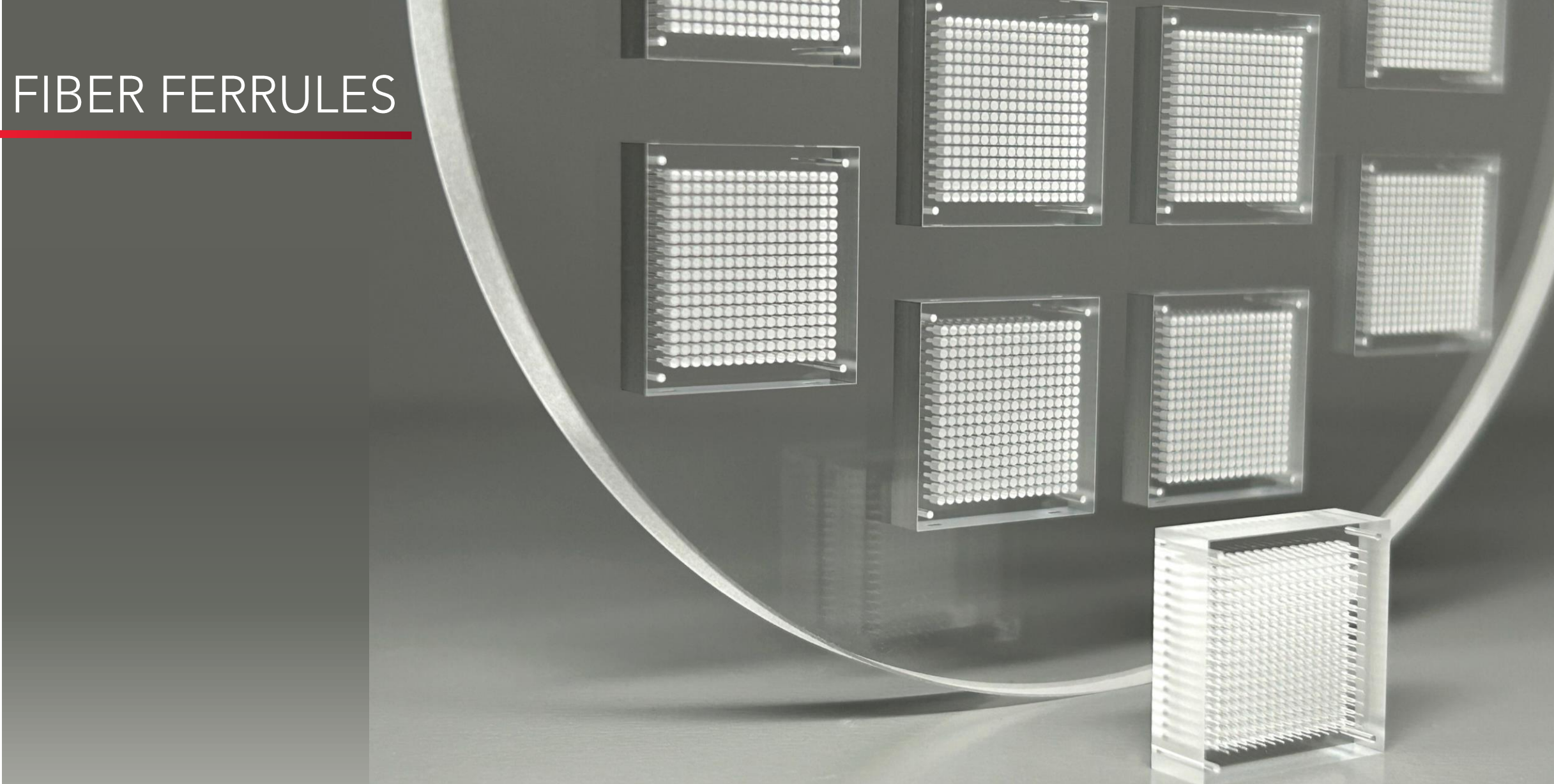
FIBER-TO-CHIP CONNECTIVITY

FIBER FERRULES

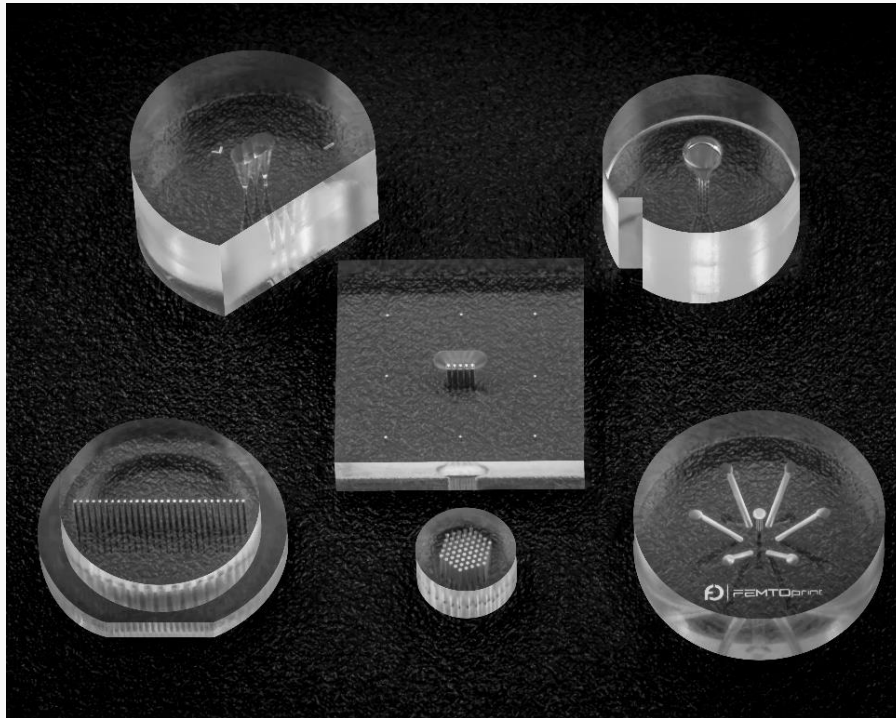
WAVEGUIDES

MICRO-OPTICS

FIBER FERRULES



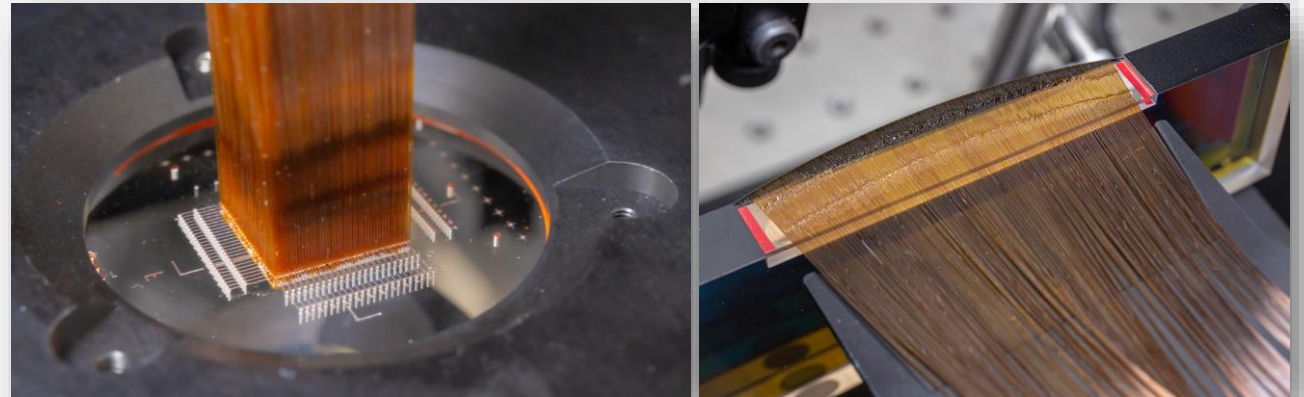
Glass ferrules for high-precision fiber alignment



MECHANICAL POSITIONING

EXAMPLE

- Integral field spectrograph for astronomical telescope
- High precision 1D and 2D fibre arrays (2400-element) & MLA coupling



Courtesy of Gábor Fűrész, MIT Kavli Institute for Astrophysics and Space Research

USPs

- Thin to thick glass ferrules for optimized mechanical stability
- Fully customizable 2D hole arrays with straight or tilted holes
- Sub- μm precision in hole diameter and positioning
- Monolithic integration with
 - mounting features
 - additional components (e.g. micro-lenses, waveguides, etc.)
- Integration of fiducials on the surface and/or in the bulk
 - Alignment precision $< 2\mu\text{m}$

Hole diameter & position

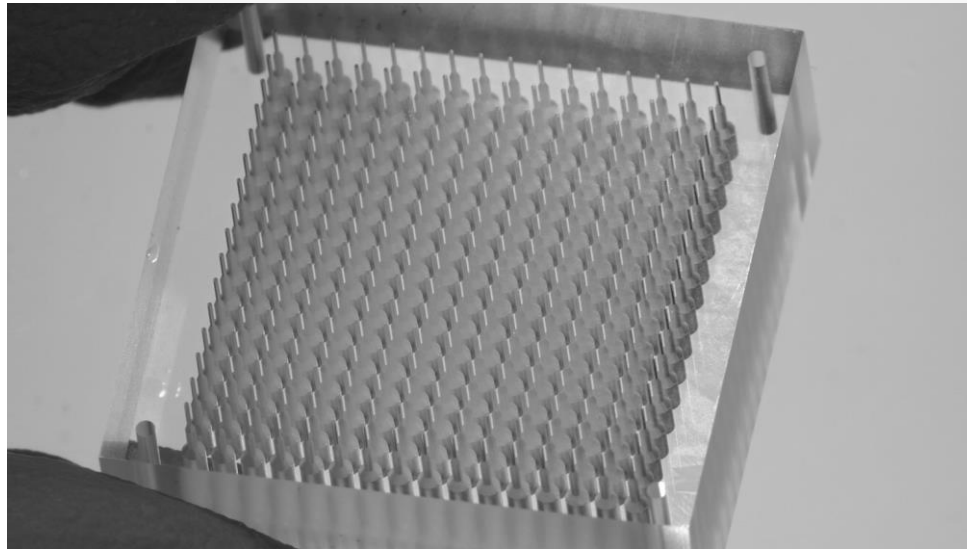
16x16 ARRAY

Fused silica

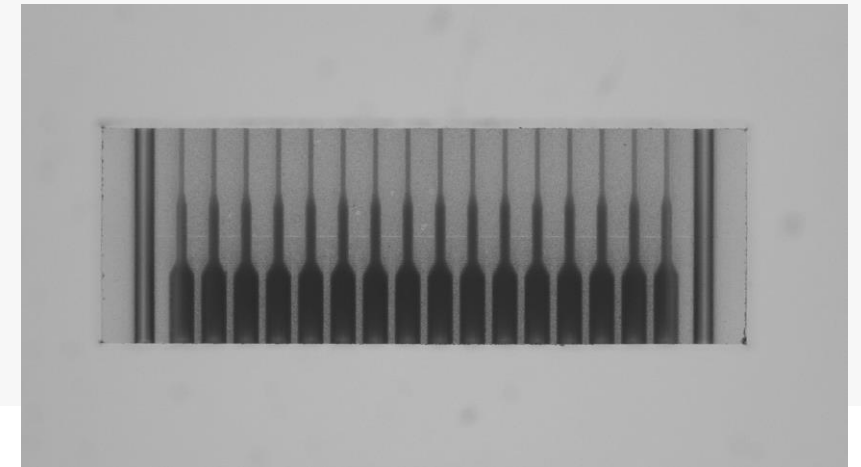
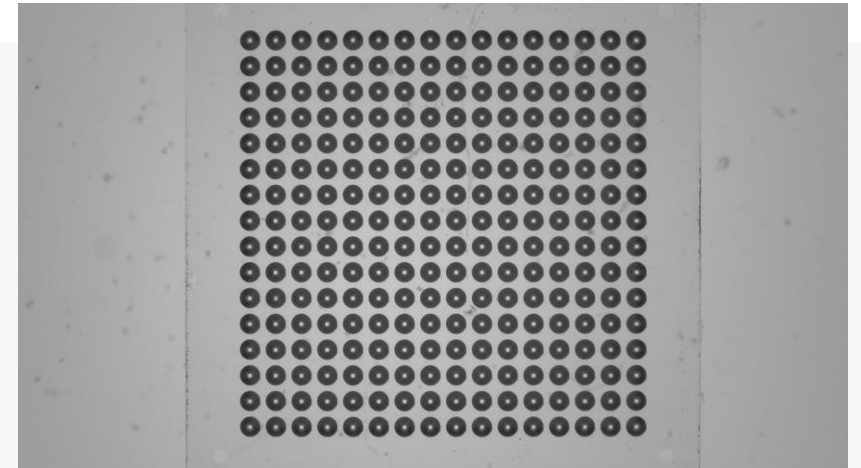
Thickness = 5 mm

Pitch = 0.75 mm

Target diameter = 0.1255 mm

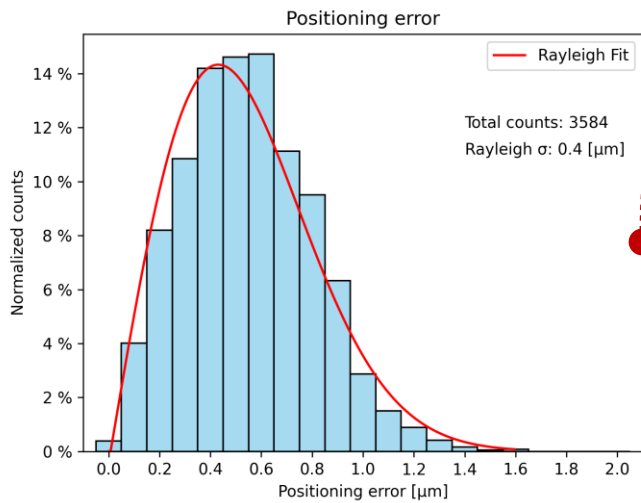
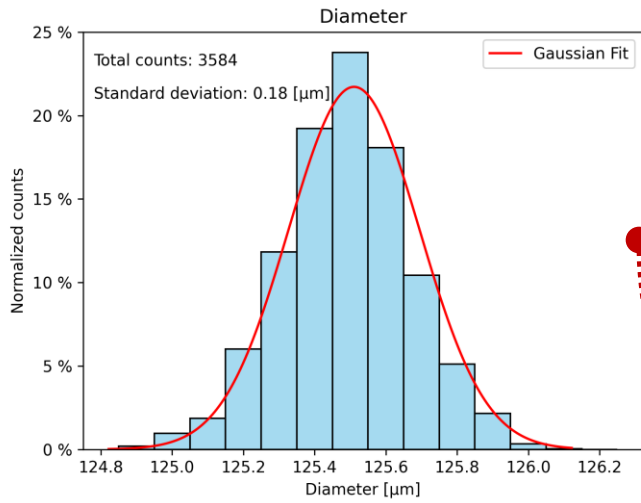


MECHANICAL POSITIONING

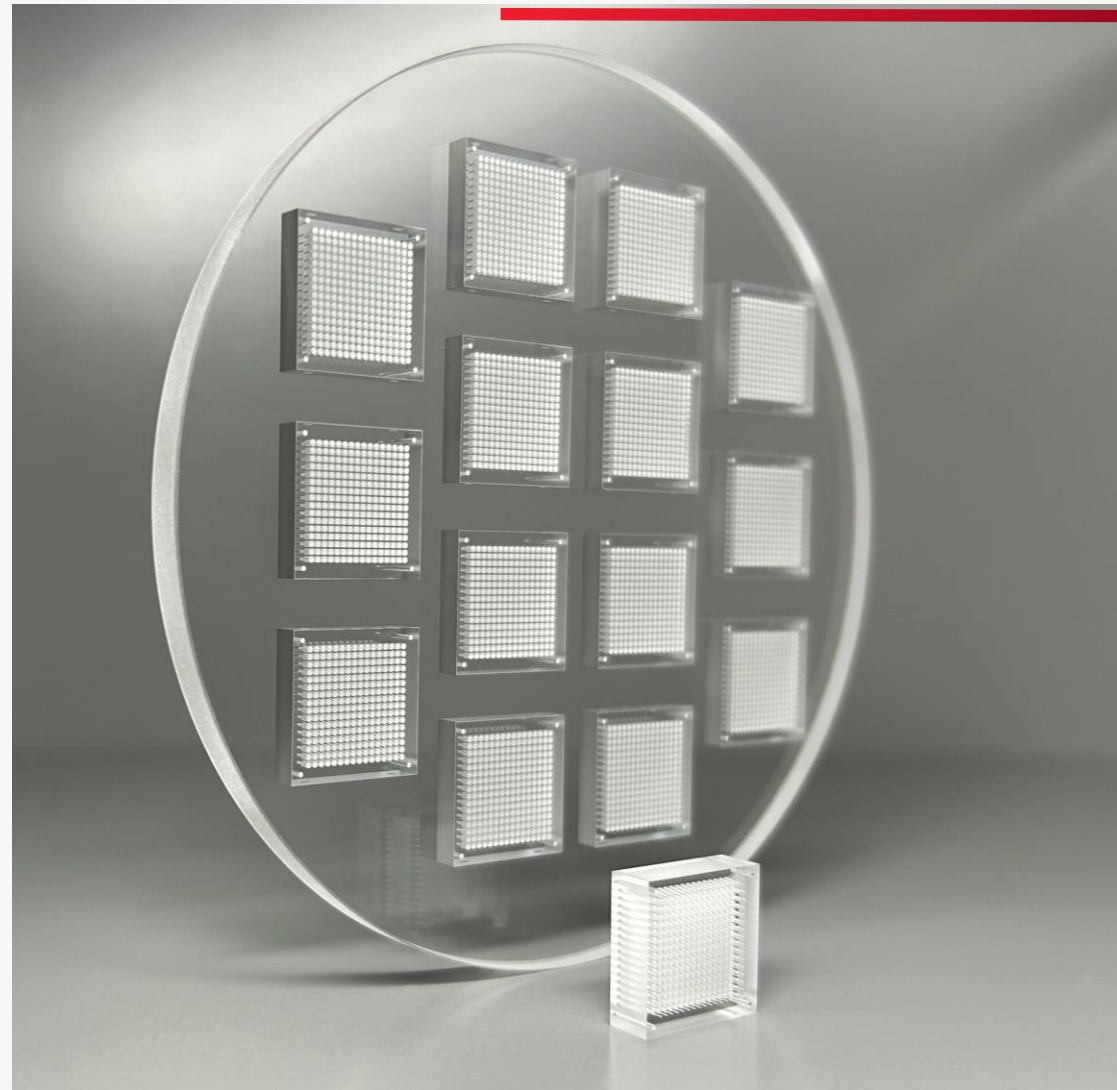


Hole diameter & position

MECHANICAL POSITIONING



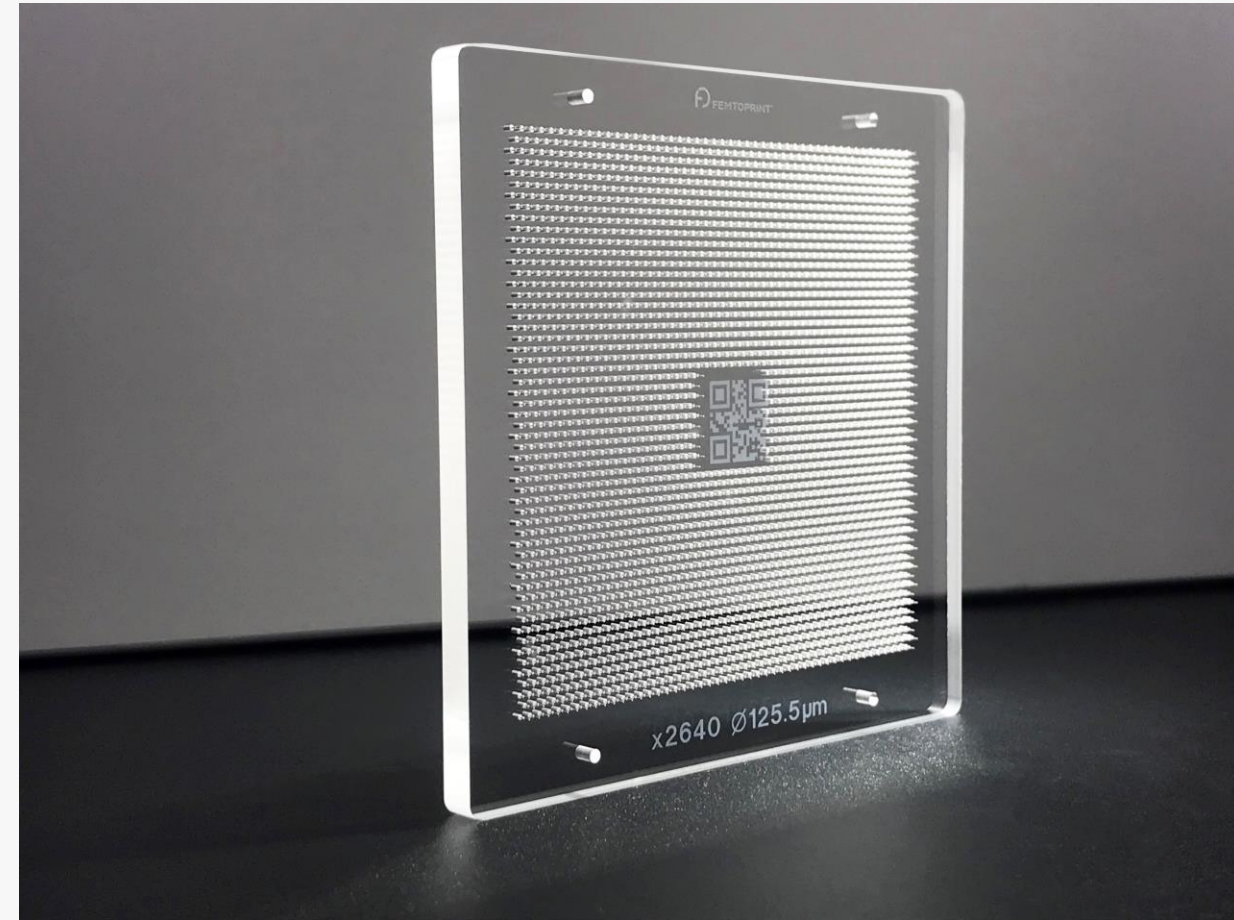
Sub- μm control



2D hole arrays for high-precision fiber ferrules

- Available on various substrates
 - Fused silica (FS)
 - ➔ thermal match with silica fibers
 - Borofloat 33 (BF33)
 - ➔ thermal match with SiPh
- Available with a large range of thicknesses
 - typically 3 - 7mm
 - ➔ enhanced mechanical robustness
- Tailored hole shapes with multiple sections:
 - e.g. core-cladding, coating, jacket
 - ➔ enhanced stability
- Tilted holes
 - ➔ reduced Fresnel losses
 - ➔ improved grating in-coupling

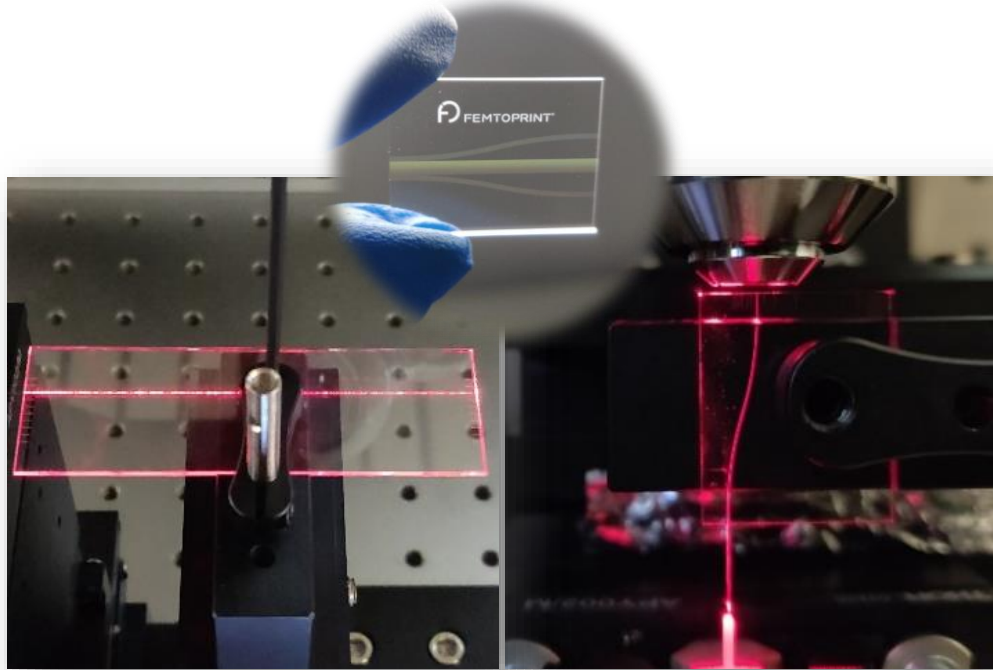
MECHANICAL POSITIONING



WAVEGUIDES



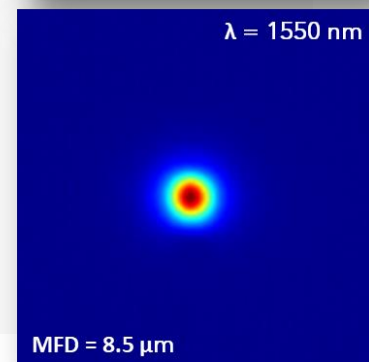
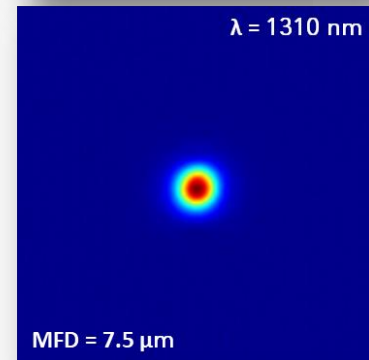
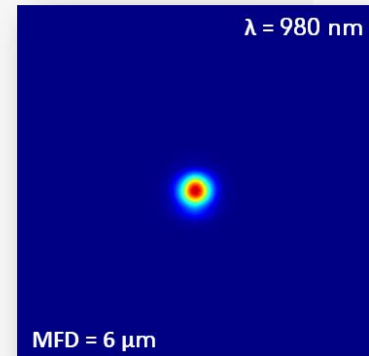
3D GLASS WAVEGUIDES



- **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 and characterization

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	$< \pm 1 \mu\text{m}$
Min. Bending Radius	$\leq 20 \text{ mm}$
Propagation Loss	$\leq 0.2 - 0.3 \text{ dB/cm}$
Δn	$10^{-2} - 10^{-3}$

LIGHT GUIDING



MICRO-OPTICS

 FEMTOPRINT®

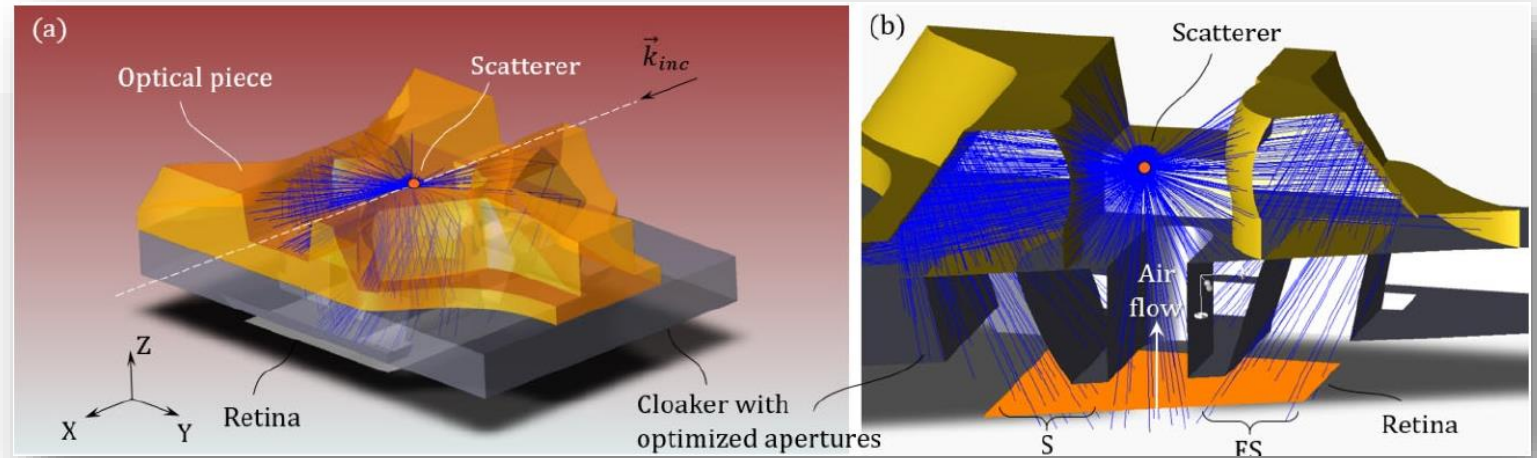


APPLICATION

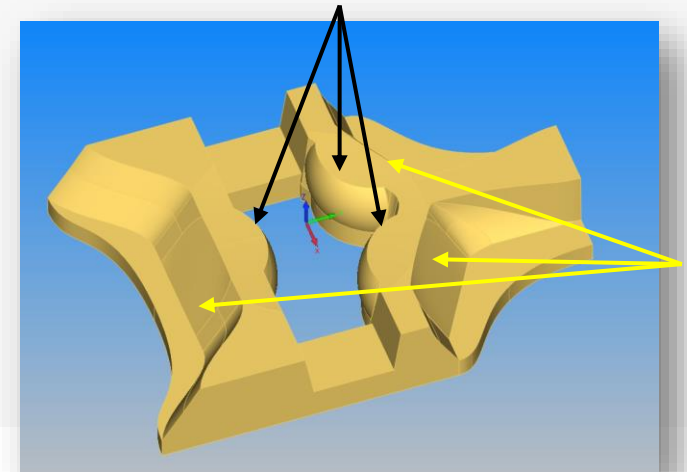
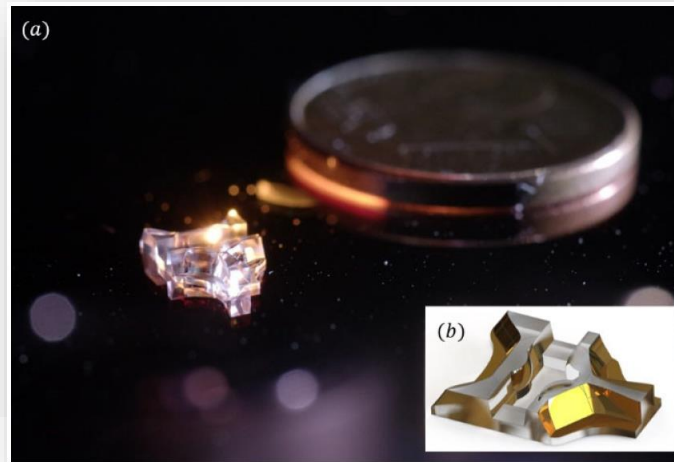
- Air quality monitoring
- Improved sensitivity
- Integration of a miniaturized refractive/reflective optical system

USPs

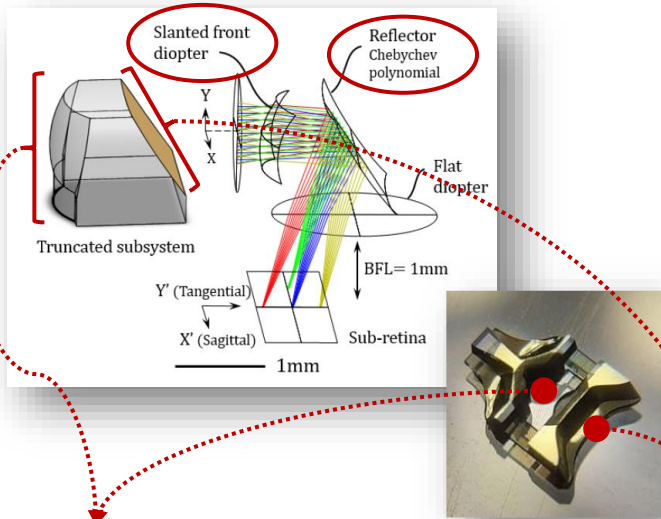
- Monolithic integration
- 3D free-form fabrication
- Miniaturized optics



Slanted diopters

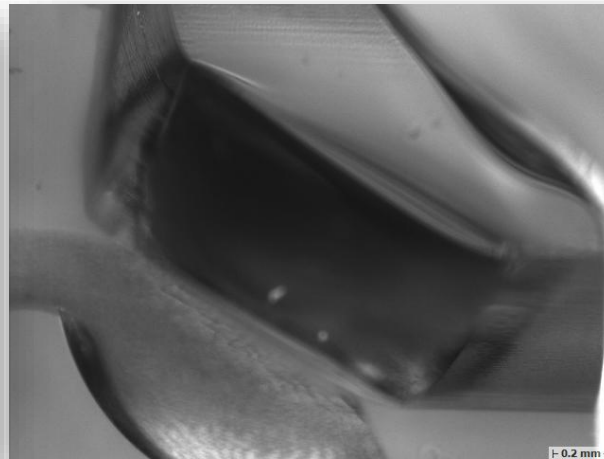
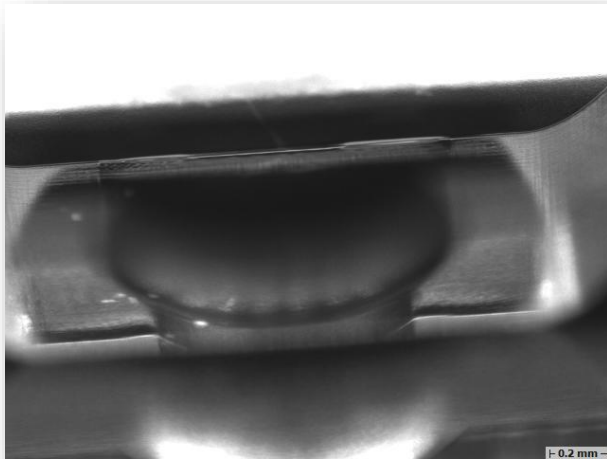


Free-form reflectors

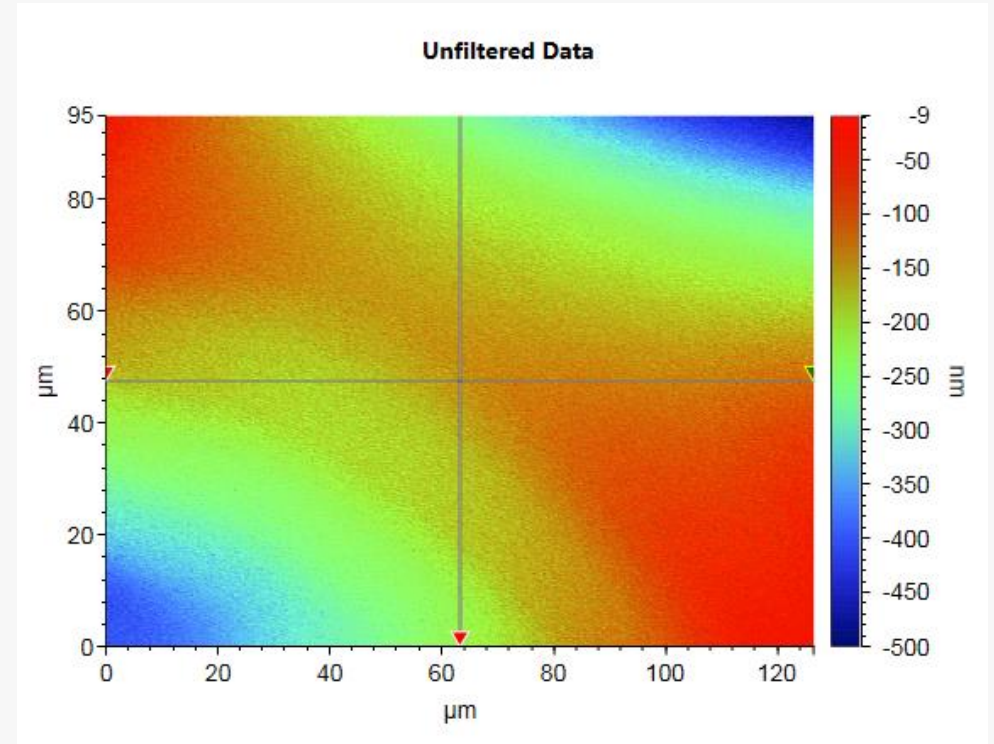


Slanted diopter

Free-form reflector



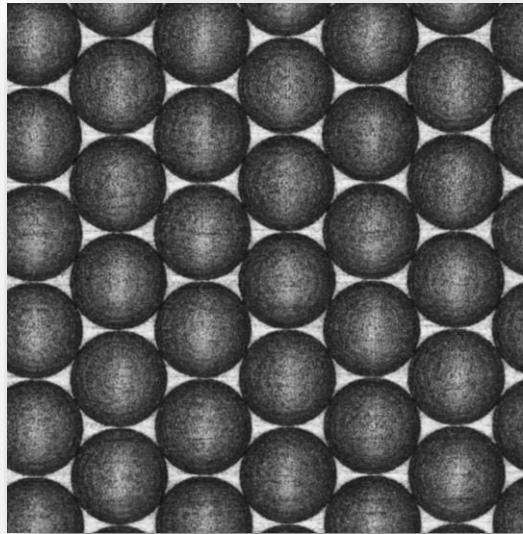
Interferometric image of the reflector surface



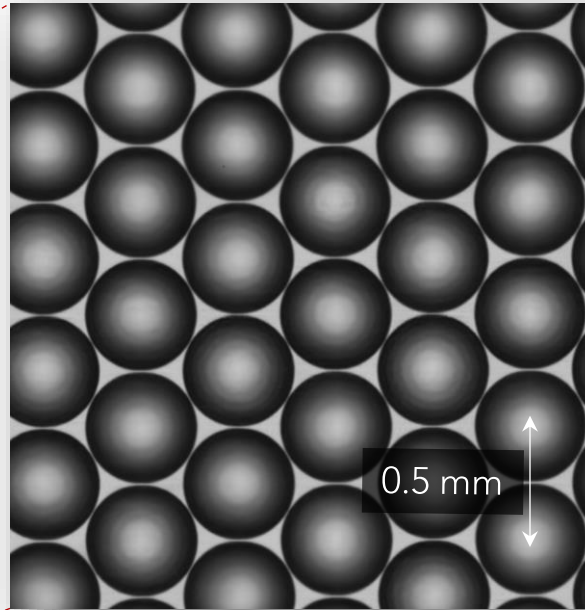
Surface roughness: $S_a = 6\text{nm}$

Hexagonal closely packed MLA 100x spherical micro-lenses

- Diameter = $500 \mu\text{m}$
- RoC = $650 \mu\text{m}$
- SAG = $50 \mu\text{m}$



Without surface processing



With surface processing

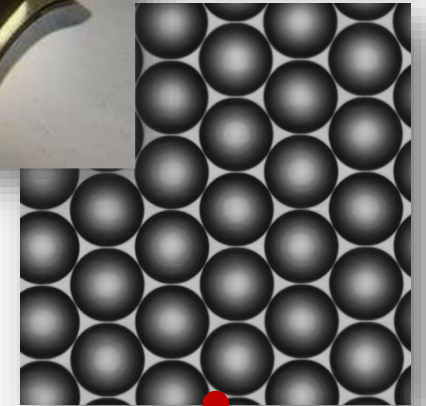
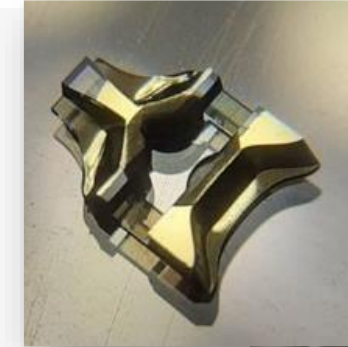
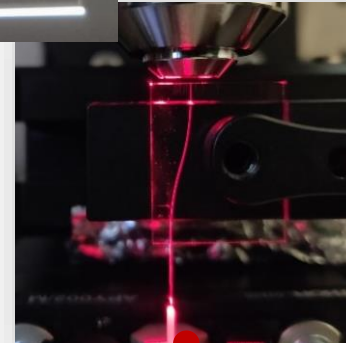
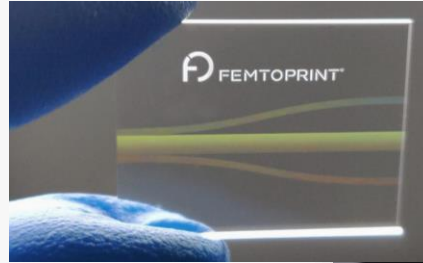
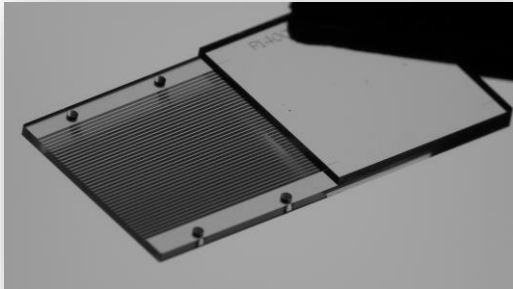
Micro-machined MLAs in Fused Silica

- RoC = $625 \pm 5.0 \mu\text{m}$
- SAG = $51.1 \pm 1.5 \mu\text{m}$
- Sa = $4.8 \pm 3.3 \text{ nm}$
- Shape accuracy: $< 1.5 \mu\text{m}$

HIGH-PRECISION FIBER ALIGNMENT

BEAM ROUTING

BEAM SHAPING



- $< \pm 1\mu\text{m}$ relative positioning
- Monolithic integration of several functionalities
- Optical systems for fiber-to-chip connectivity

Thank you!

The Art of
uMANUFACTURING

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