FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

Laser-based Micro-machining for Micro-Optics:
The New Frontier for 3D Wafer-scale Manufacturing

Rolando Ferrini

SWISS PHOTONICS

Workshop on Microoptics
Microcity EPFL – Neuchâtel, November 7th, 2022

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swiss made

Management System EN ISO 13485:2016
TÜVRheinland CERTIFIED
www.tuv.com ID 9108638488

FEMTOprint IN A NUTSHELL

FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

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

FOUNDED IN 2013
Spin-off of the EU project *femtoprint*

> 35 FTEs
Interdisciplinary and multicultural team

2 LOCATIONS IN SWITZERLAND
Muzzano (*Headquarters)* & Neuchâtel (*BU Photonics)*

WORLDWIDE SALES
Export in 30+ countries & Sales agents in KR, JP, IL, DACH

ISO CERTIFIED
ISO 13485 : 2016

GLASS

01 TRANSPARENT AND ISOTROPIC

02 STABLE AND ELECTRICALLY INSULATING

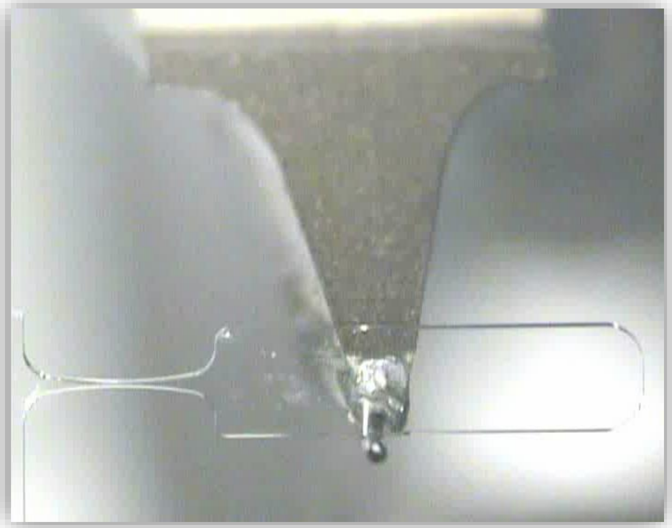
03 BIOCOMPATIBLE

04 ELEVATED THERMAL PROPERTIES

05 HIGHLY ELASTIC

06 RESISTANT TO CORROSION, ABRASION AND SCRATCHES

07 NEUTRAL TO MAGNETIC FIELDS



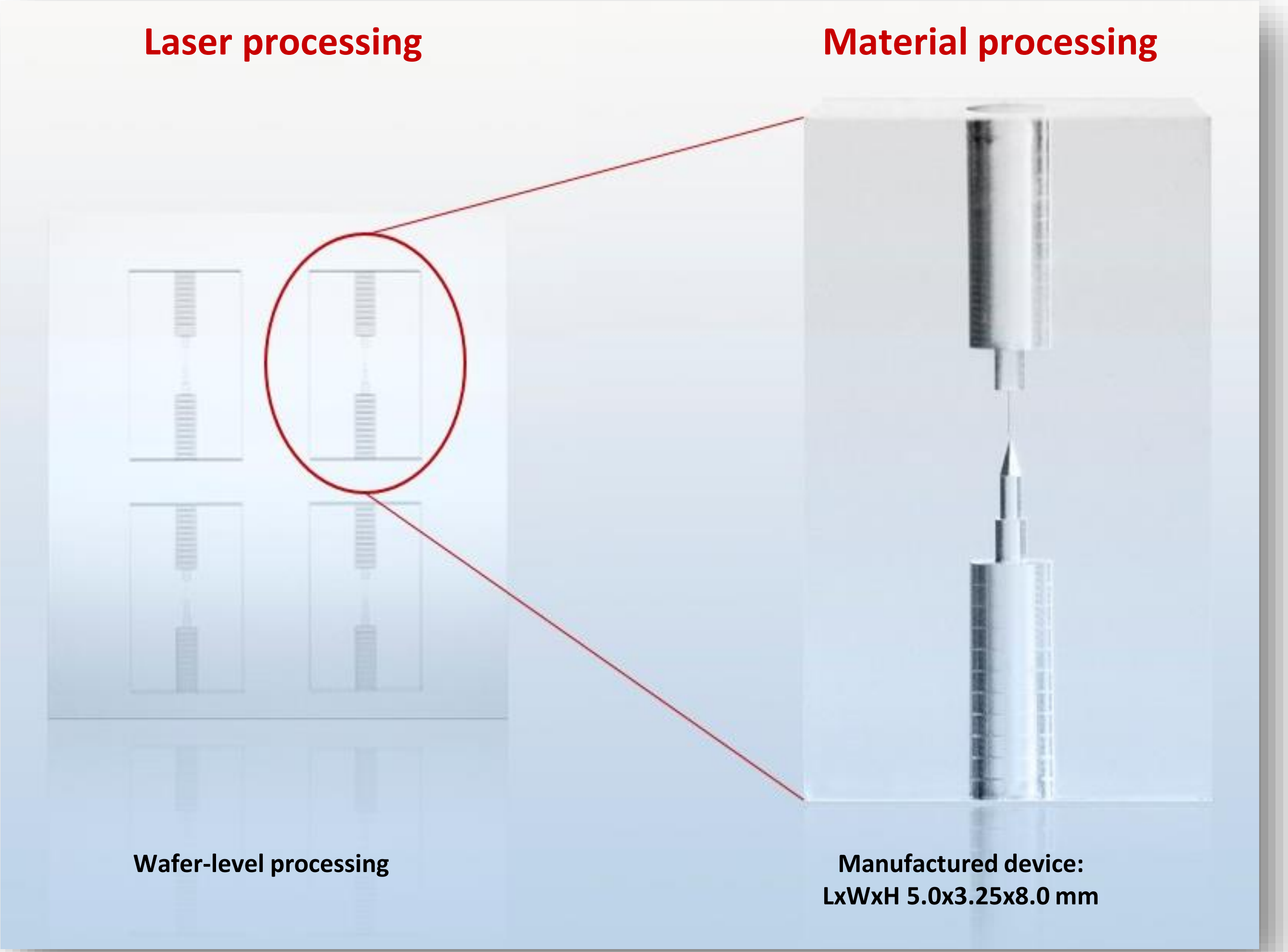
LASER-BASED MICRO-MANUFACTURING

LASER 3D MICROFABRICATION

- laser-based microstructuring & material processing
- free-form 2D/3D microprocessing in glass materials

WHY WORKING WITH US

- In-house unique know-how and capabilities of glass micro-processing, from proof-of-concept, to pilot and series manufacturing;
- Vertically integrated, one-stop shop manufacturing foundry, delivering from single units up to volumes on wafer-level;
- Control over the entire value chain and fast turnaround cycles in prototyping;
- ISO 13485:2016 certified for medical devices;
- Suitable for numerous glass types: fused silica, fused quartz, borosilicate, aluminosilicate, alkali-free, etc.



3D MANUFACTURING OF GLASS MICRO-DEVICES

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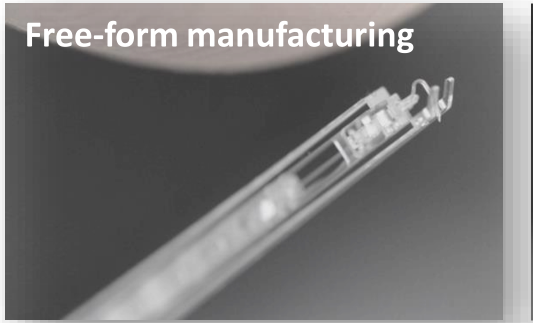
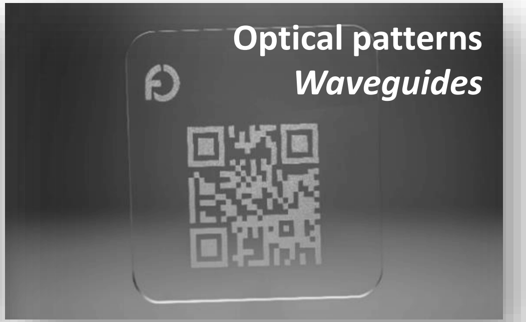
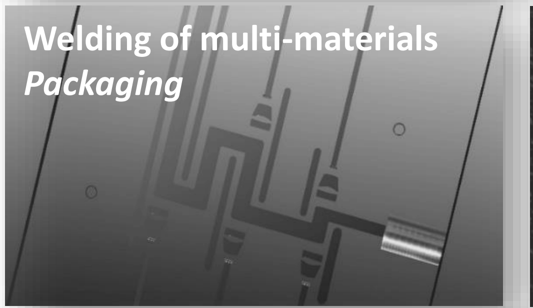
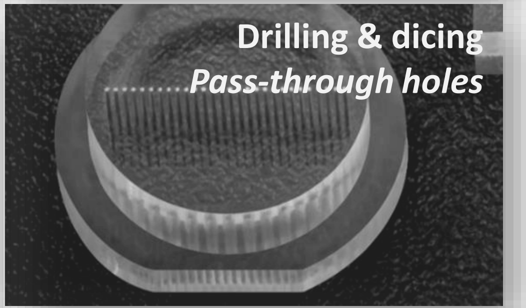
3D PRINTING FOR GLASS MICRODEVICES

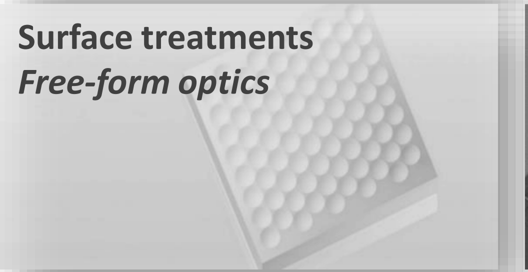
CAPABILITIES

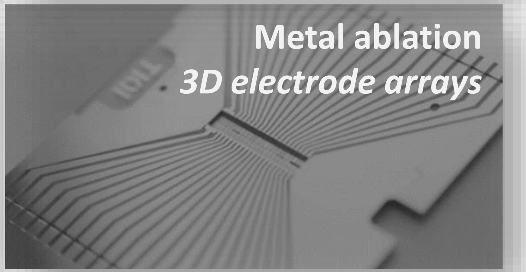










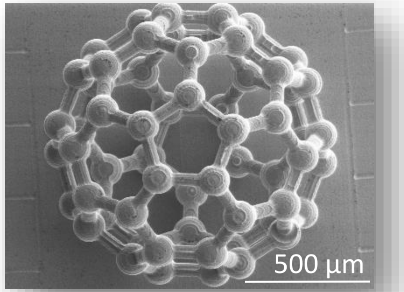


PERFORMANCES*

*in SiO2

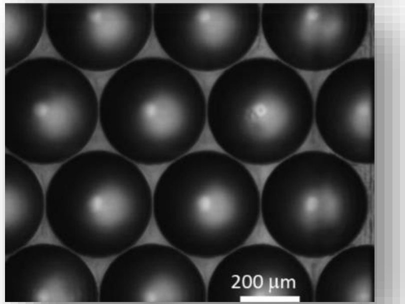
RESOLUTION AND TOLERANCES

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



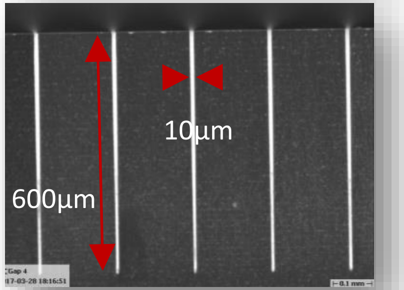
SURFACE QUALITY

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

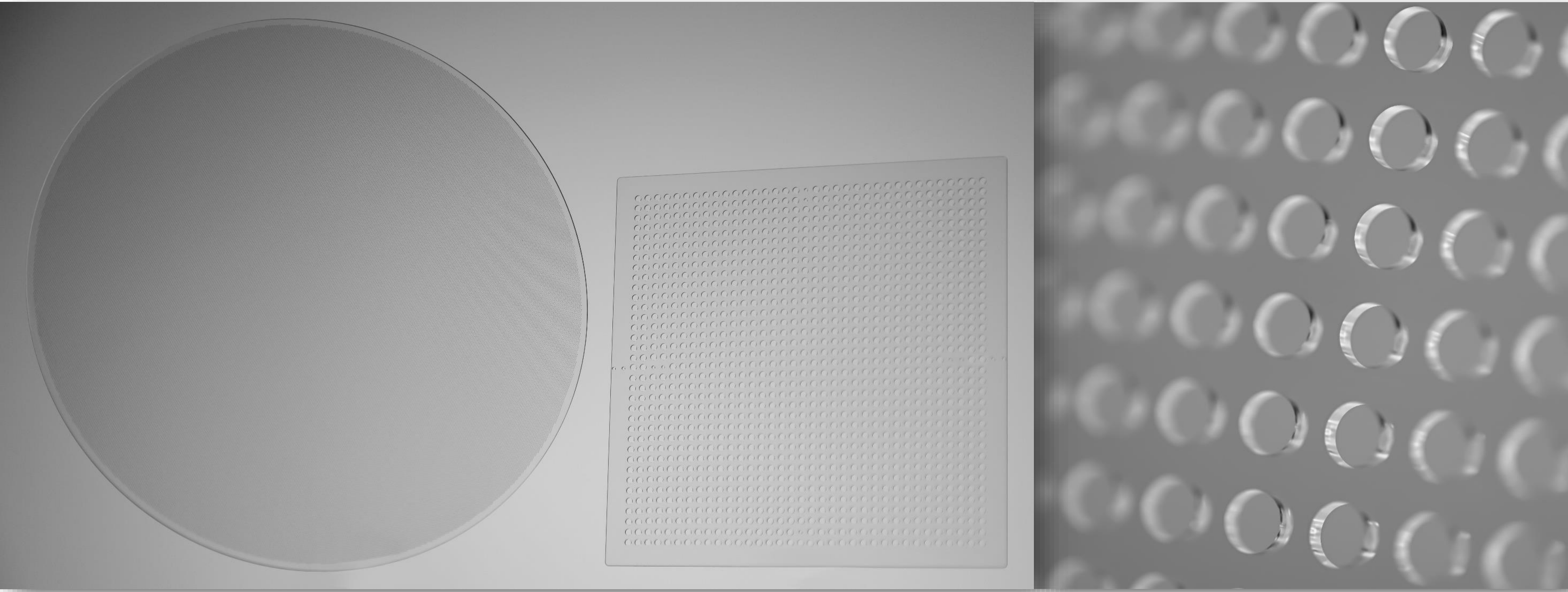


ASPECT RATIO

- Hole aspect ratio ≥ 1:500
- Substrate thickness up to 30 mm
- Min. hole diameter ≤ 5 µm Ø
- Sidewall deviation ≤ 0.1°
- Sidewall roughness *Sa* ≤ 100 nm



MICRO-MANUFACTURING AT WAFER-LEVEL



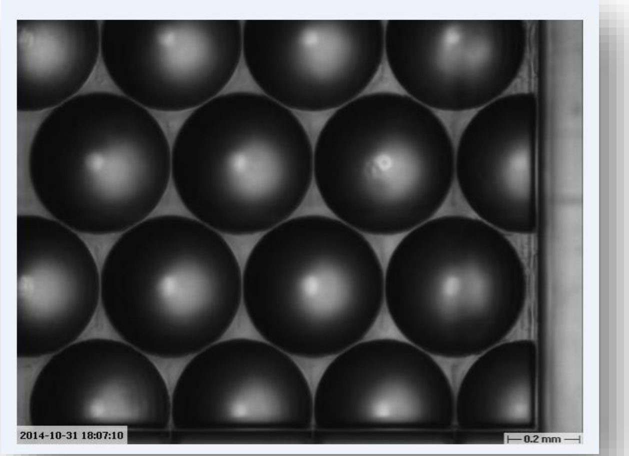
MICRO-OPTICS

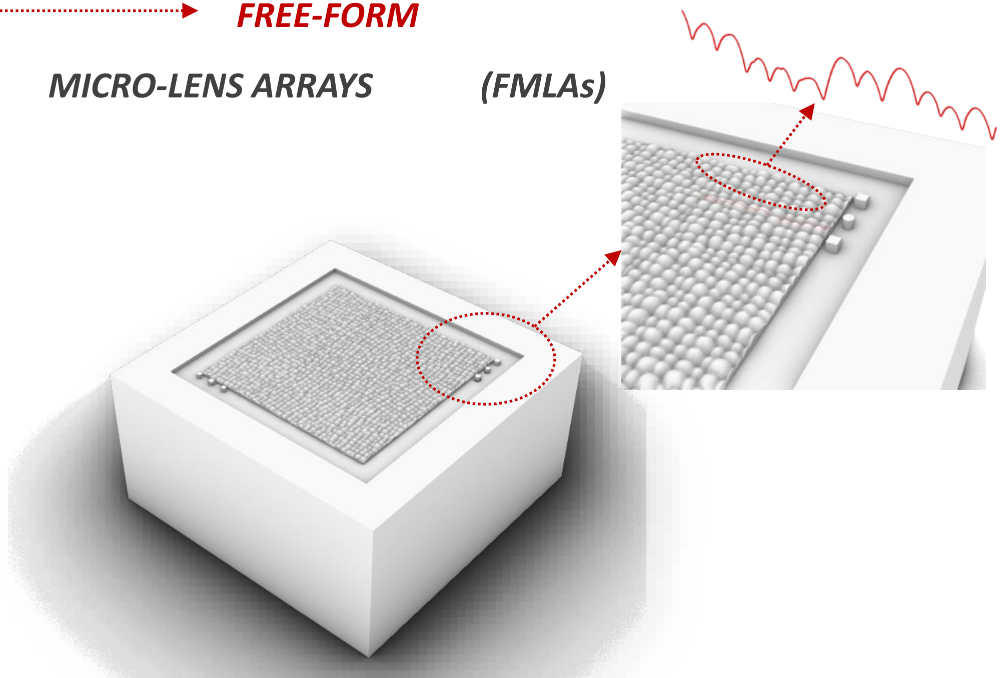
SPHERICAL or ASPHERICAL → *NON-SPHERICAL* → *FREE-FORM*

MICRO-LENSES & MICRO-LENS ARRAYS (MLAs)

MICRO-OPTICAL ARRAYS

MICRO-LENS ARRAYS (FMLAs)





Engineered diffuser (SAG = 75 μm)
Courtesy CSEM

Feasibility → **Fast prototyping** → **Pilot manufacturing** → **Small-to-medium volume production** → **ORIGINATION & TOOLING**

DEVELOPMENT: rapid cycles from concept to prototypes and small-to-medium product series

Enabling large volume production

MICRO-OPTICS – FROM SPHERICAL TO FREE-FORM MLAs

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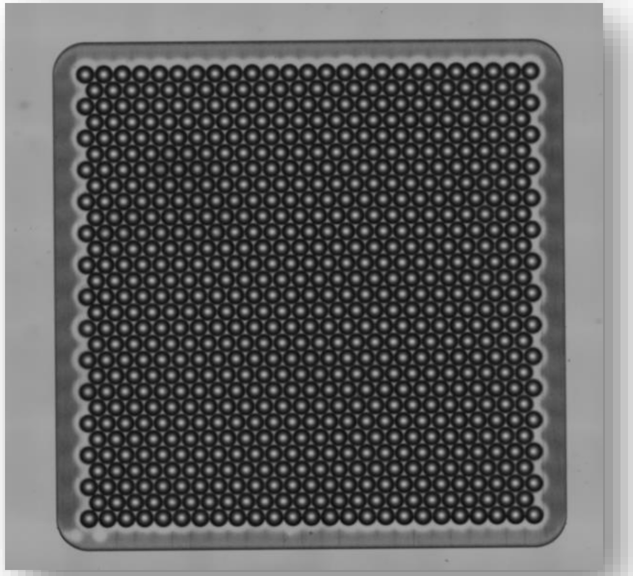
Flat surfaces

- *Surface roughness Sa* < 10 nm

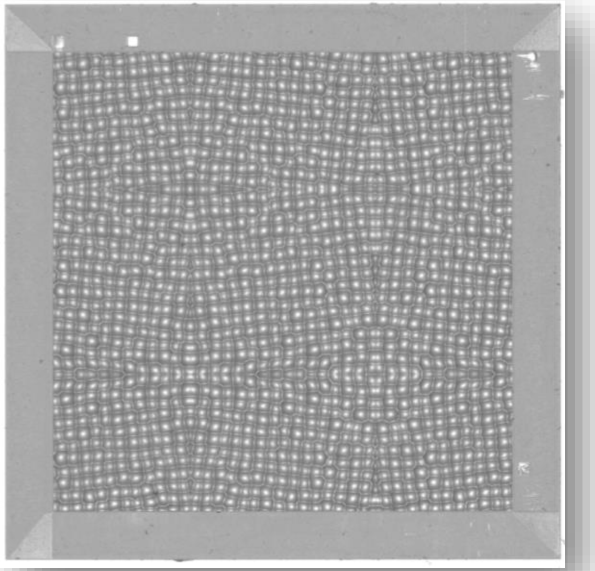
(A)spherical Micro-Lens Arrays

- *Sa* ≤ 10-20 nm
- Shape accuracy ≤ 1-3 µm



Free-form Micro-Lenses Arrays

- *Sa* ≤ 20 nm
- Shape accuracy ≤ 2-3 µm



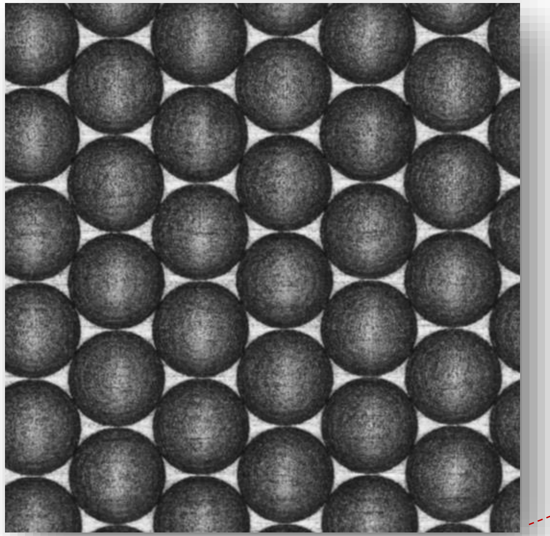
Innosuisse Project (n. 35418.1 IP-ENG)
Smart LAser Manufacturing for precision industry 4.0 (SLAM 4.0)

MICRO-OPTICS – "SMALL" SPHERICAL MLAs

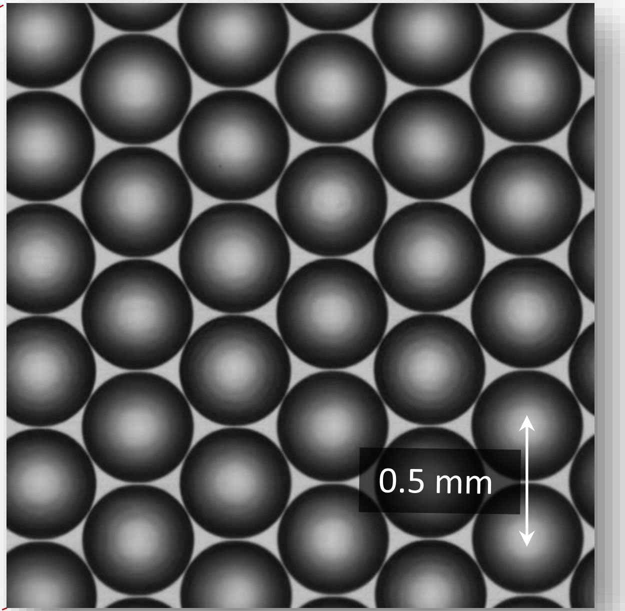
Hexagonal closely packed MLA

***100x* spherical micro-lenses**

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



Without surface processing



With surface processing

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

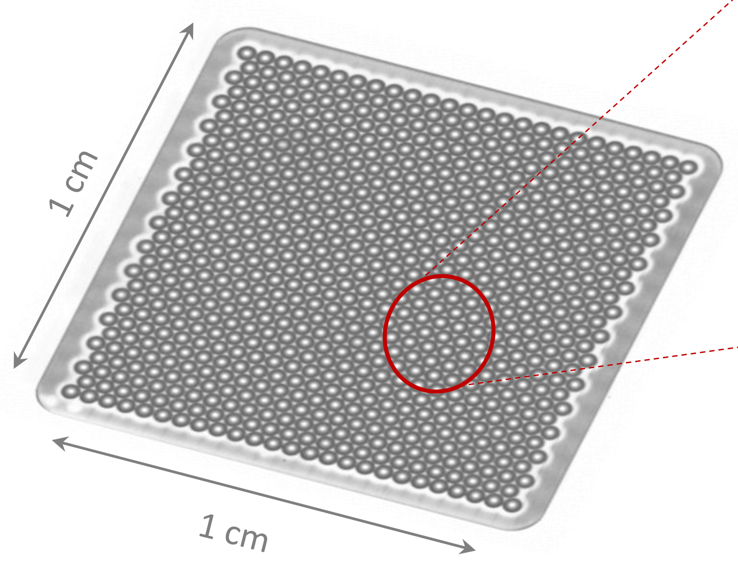
MICRO-OPTICS – “LARGE” SPHERICAL MLAs

FEMTOPRINT
3D PRINTING FOR GLASS MICRODEVICES

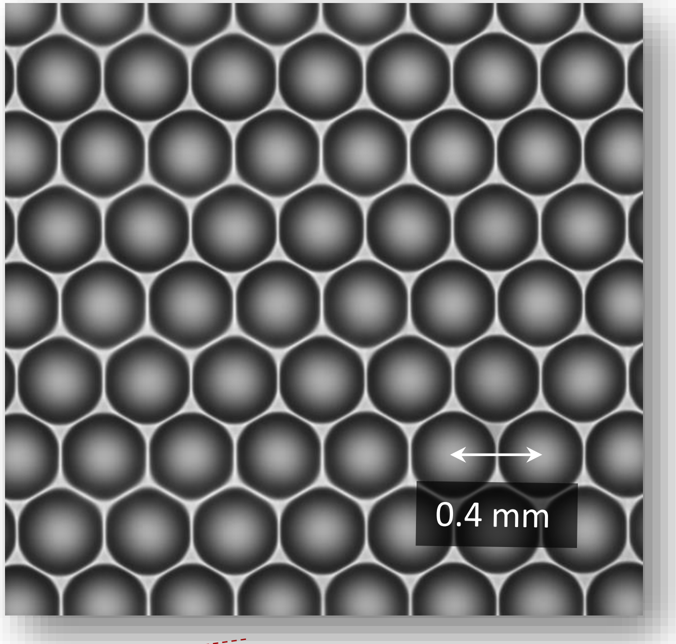
Hexagonal closely packed MLAs

***700x** spherical micro-lenses*

- *Diameter = 390 μm*
- *RoC = 500 μm*
- *SAG = 39.6 μm*



With surface processing



Micro-machined MLAs in Fused Silica

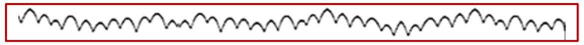
- RoC = 505.5 ± 12.0 μm
- SAG = 38.9 ± 0.9 μm
- *Sa* = 7.4 ± 1.3 nm
- Shape accuracy: < 1.5 μm

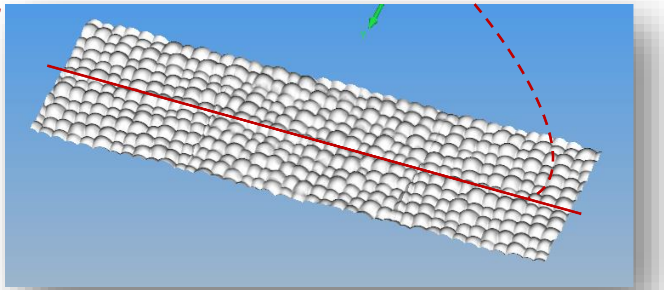
MICRO-OPTICS – “VERY LARGE” FREE-FORM MLAs

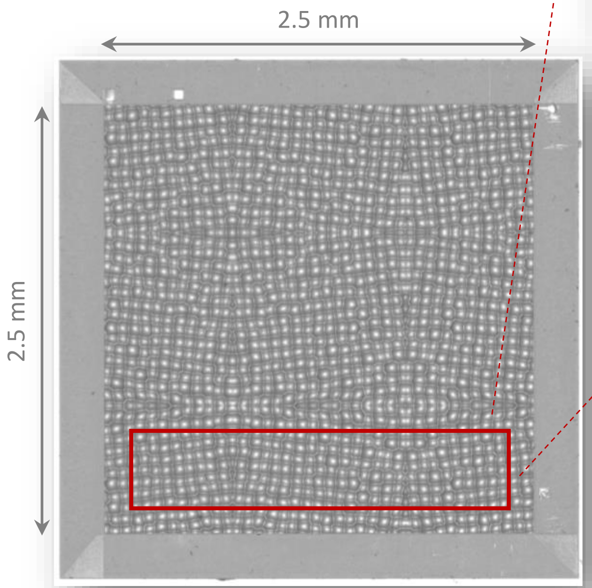
Free-form MLA diffuser

<u>1000x</u> free-form micro-lenses

- *Diameter = 50-70 µm*
- *SAG up to 70 µm*

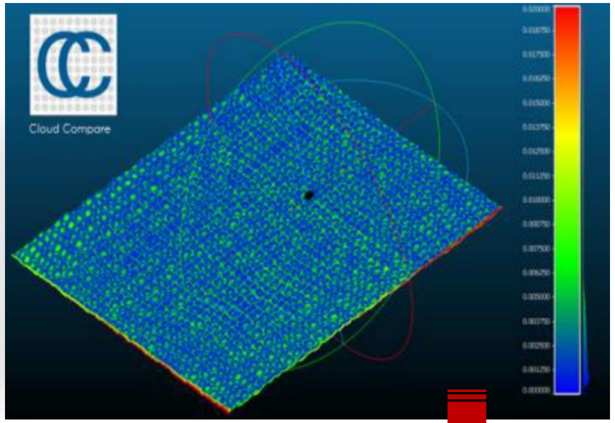






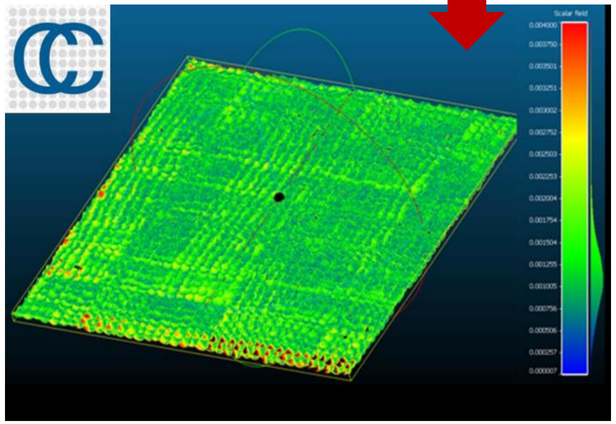
Engineered FMLA diffuser – Courtesy CSEM

Micro-machined FMLAs in Fused Silica



Without surface processing

- Sa ≈ 250 nm
- Avg surf dev: +0.08 ± 1.27 µm



With surface processing

- Sa < 20 nm
- Avg surf dev: +0.15 ± 1.71 µm

Innosuisse Project (n. 35418.1 IP-ENG) : Smart LAser Manufacturing for precision industry 4.0 (SLAM 4.0)

MINIATURIZED OPTICS

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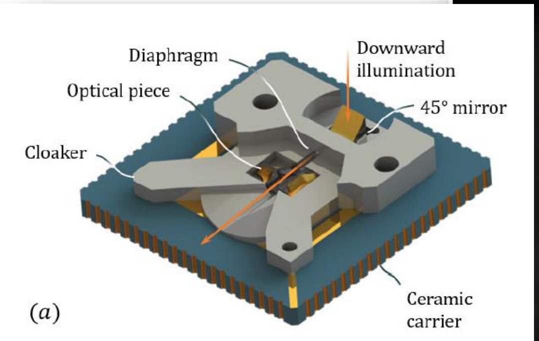
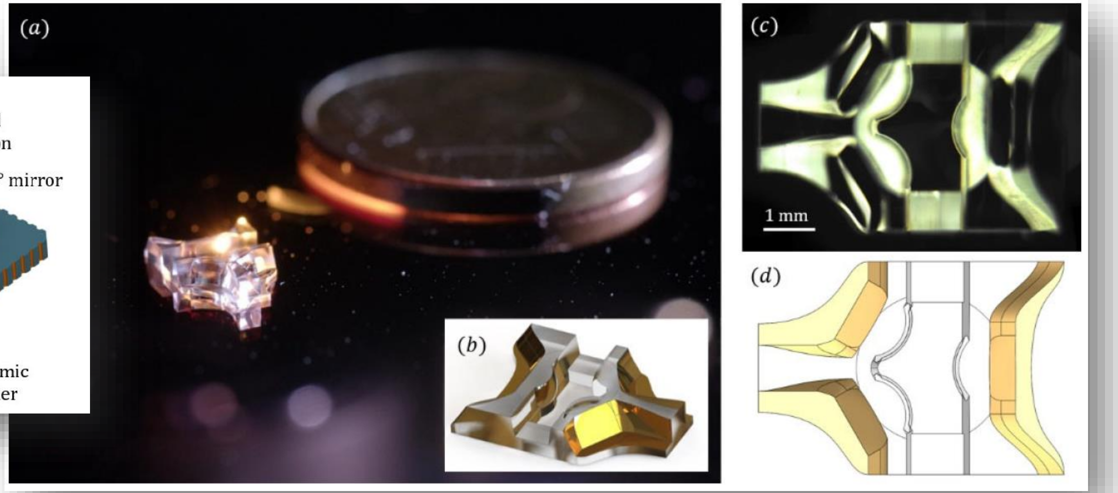
APPLICATION

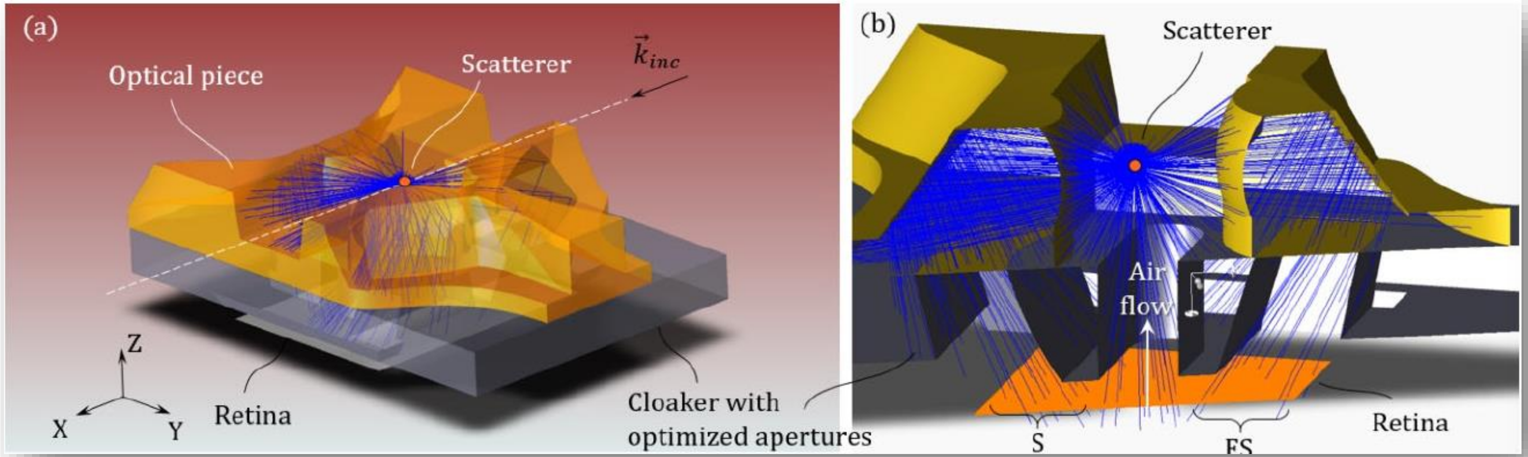
- Air quality monitoring
- Improved sensitivity by the integration of a miniaturized refractive/reflective optical system

USPs

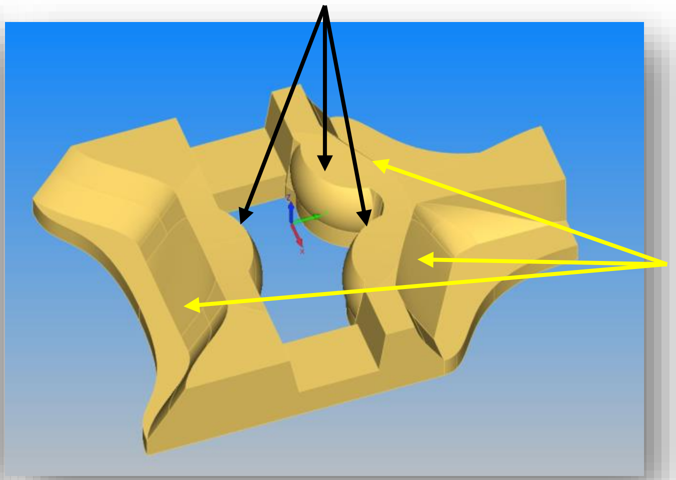
- Monolithic integration of optical functions
- Free-form fabrication in 3D
- Co-packaged miniaturized optics







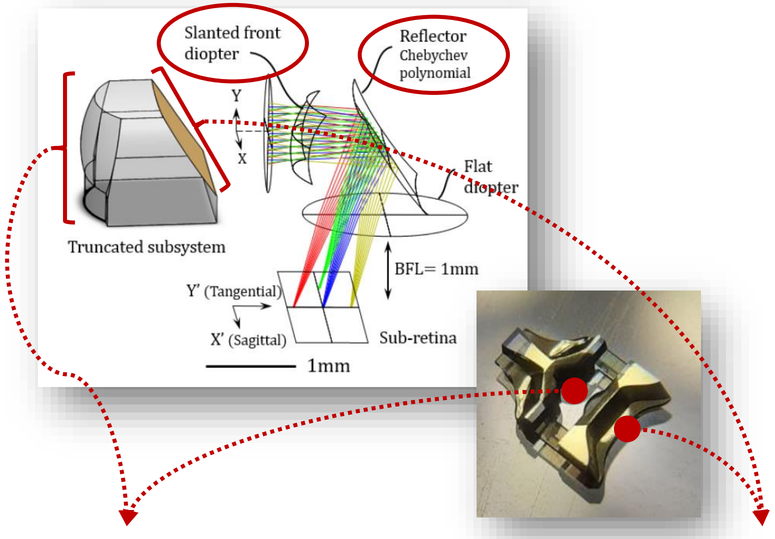
Slanted diopters



Free-form reflectors

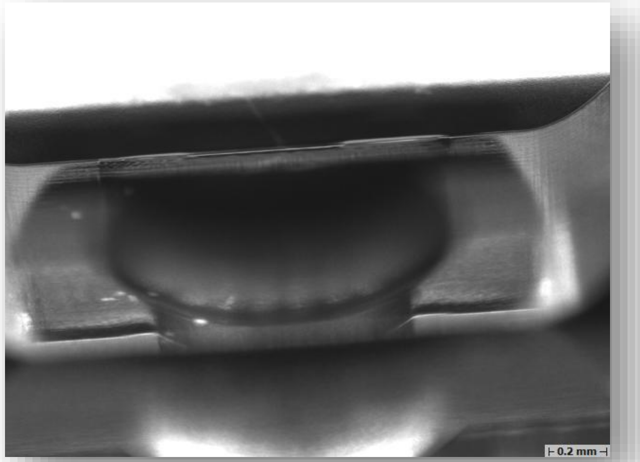
CEA-LETI Minatec & Institut des Nanotechnologies de Lyon.
Jobert G. et al. Miniature Optical Particle Counter and Analyzer Involving a Fluidic-Optronic CMOS Chip Coupled with a Millimeter-Sized Glass Optical System. Sensors 2021, 21, 3181.

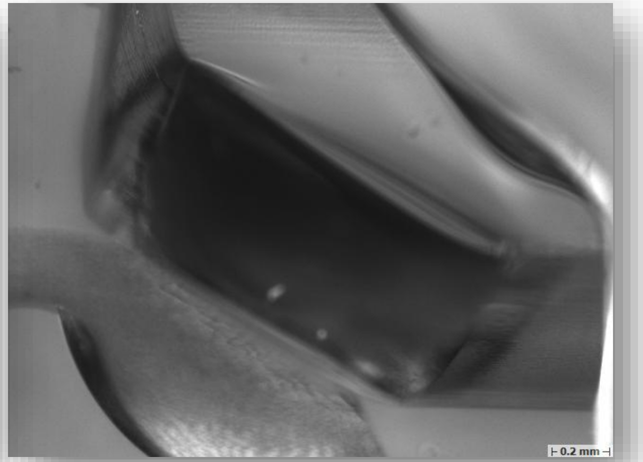
MINIATURIZED 3D OPTICAL SYSTEM



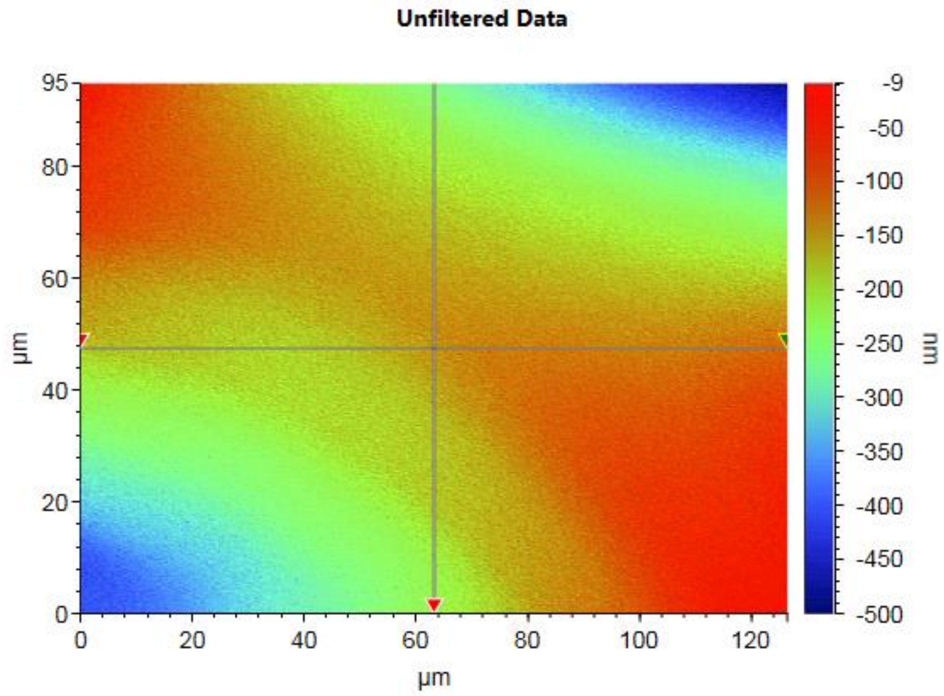
Slanted diopter

Free-form reflector





Interferometric image of the reflector surface



Surface roughness: **Sa = 6nm**

CEA-LETI Minatec & Institut des Nanotechnologies de Lyon.
Jobert G. et al. Miniature Optical Particle Counter and Analyzer Involving a Fluidic-Optronic CMOS Chip Coupled with a Millimeter-Sized Glass Optical System. Sensors 2021, 21, 3181.

ASSEMBLY & PASSIVE ALIGNMENT

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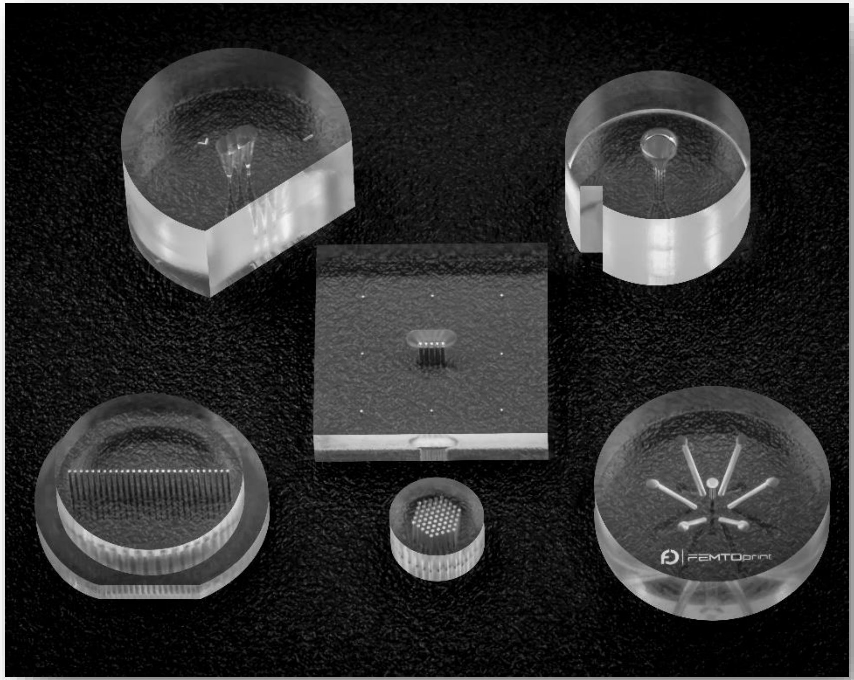
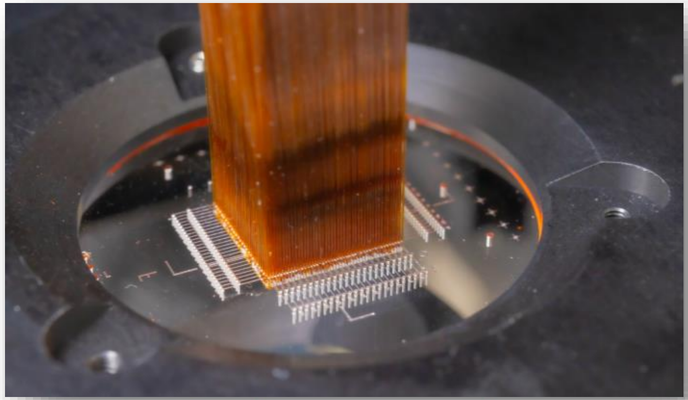
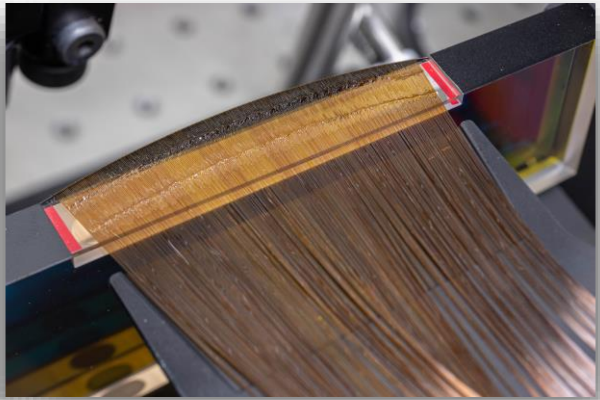
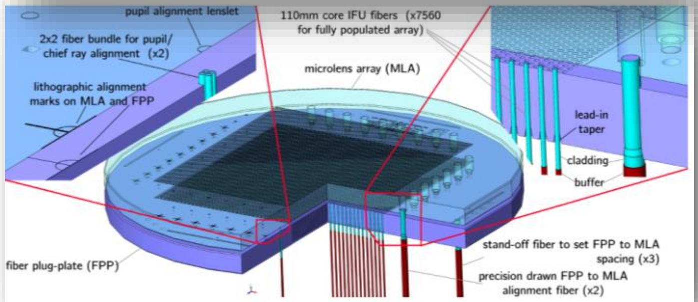
APPLICATION
- 2D fiber arrays & glass ferrules
- High precision fiber-to-chip alignment

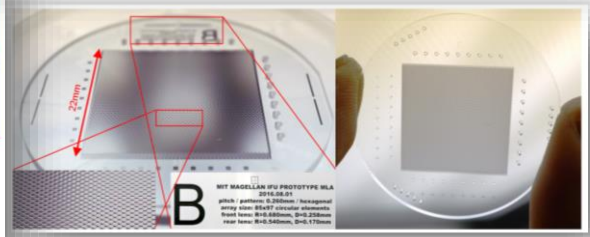


APPLICATION
- Integral field spectrograph for astronomical telescope
- High precision 1D and 2D fibre arrays (2400-element) & MLA coupling









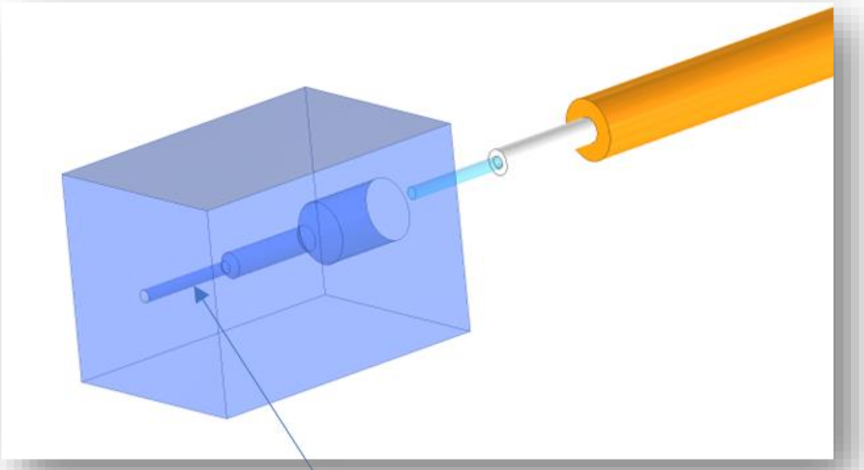
Courtesy of Gábor Fûrész, MIT Kavli Institute for Astrophysics and Space Research

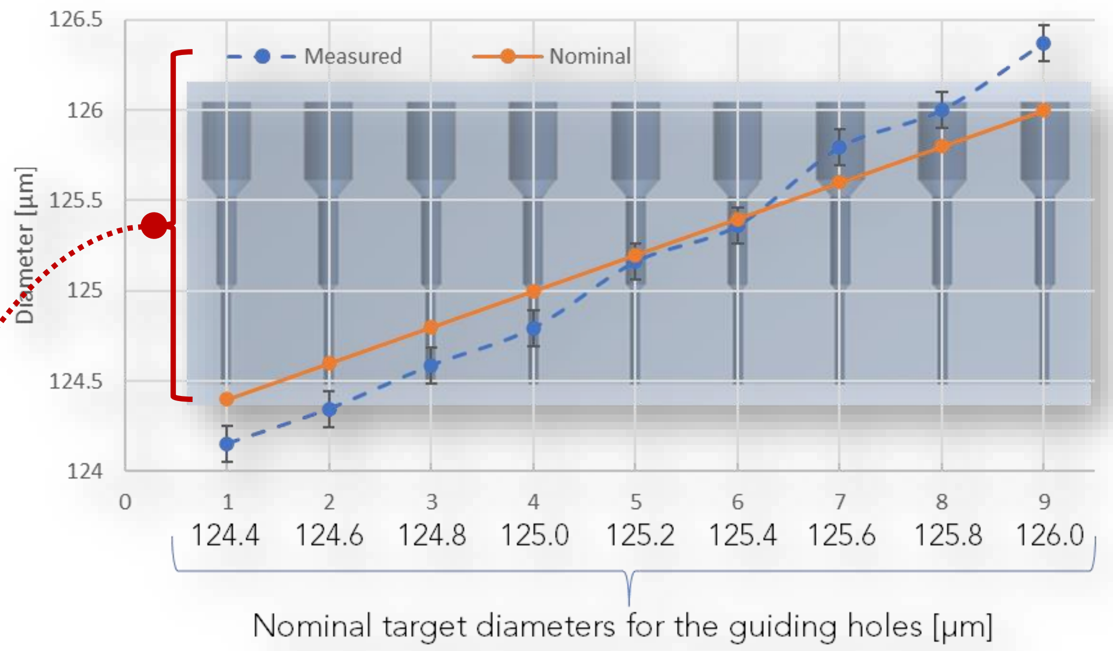
USPs
- Thin to thick glass ferrules: mechanical stability & flatness
- Customized hole arrays & additional assembly features
- Precision in hole diameter and positioning < 1 µm

FIBER FERRULES: SUB-µm CONTROL ON HOLE DIAMETER

FEMTOPRINT® 3D PRINTING FOR GLASS MICRODEVICES

- Fiber glass ferrules with varying nominal diameters of the guiding section (**steps = 0.2 µm**)
- Mechanical measurements of the effective diameter of the guiding section



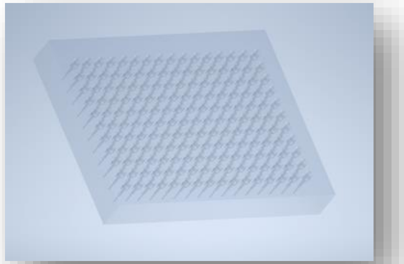


The mechanical measurements confirm that

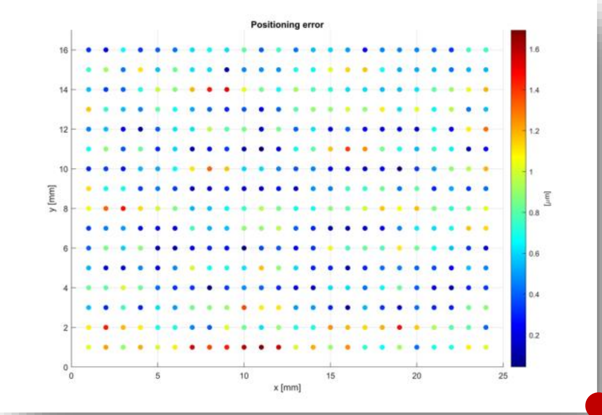
the diameters of the fabricated ferrules correspond to the nominal target values ➔ sub-µm control

FIBER FERRULES: HOLE POSITIONING

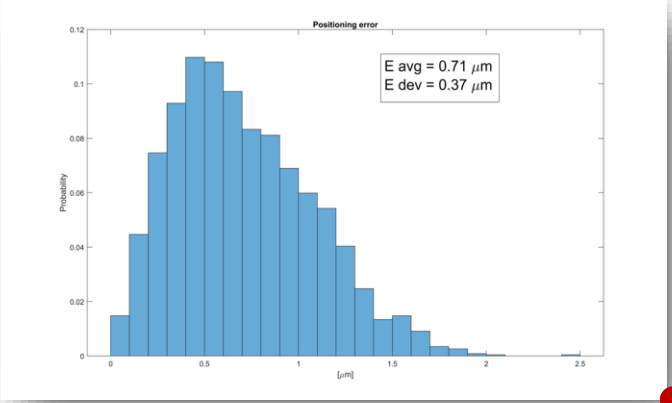
- **2D array of 24 x 16 holes**
  - Hole diameter = 125.5 µm



- **5x identical 2D arrays**



➢ Hole positioning: relative error better than the microscope resolution (± 2 µm)



➢ Average hole positioning error ± 0.7 µm

➢ Standard deviation < 0.4 µm

➢ Relative error better than the microscope resolution (± 2 µm)

Hole positioning verified on a single array

Repeatability verified on multiple arrays

PHOTONIC WIRE BONDING

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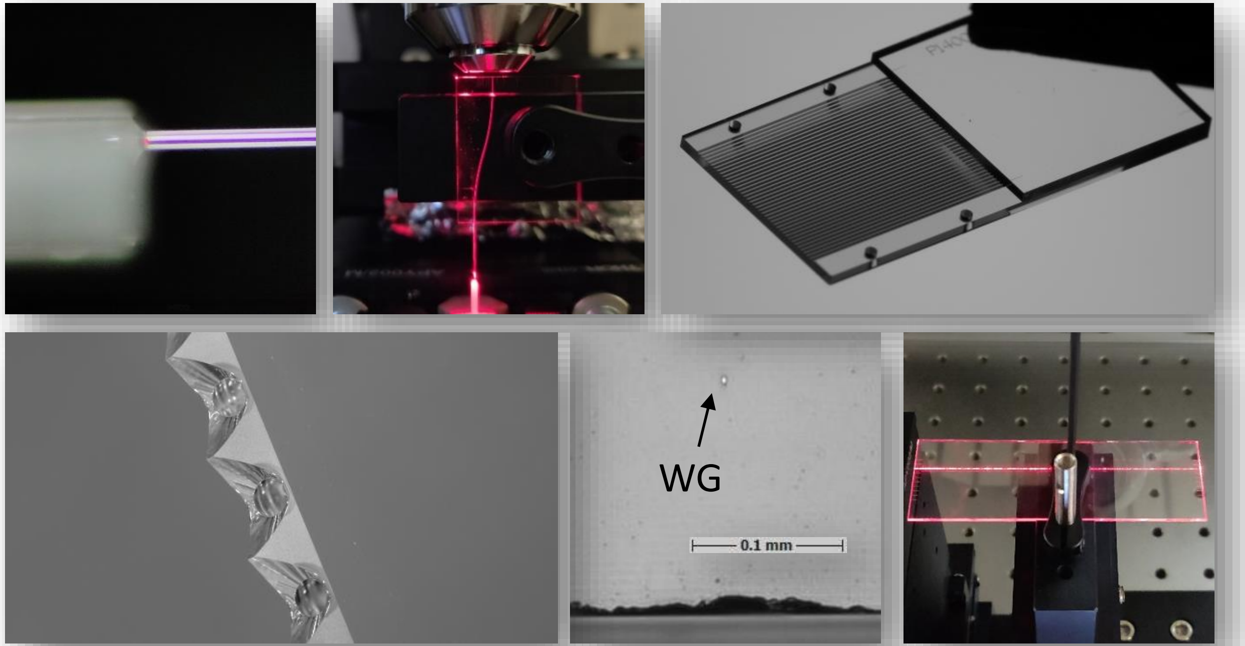

Materials	FS, BF33, EXG
Working λ [nm]	630, 980, 1310, 1550
MFD SM [μm]	3 to 9
Relative positioning	< ± 1 μm
Min. Bending Radius	≈ 25 mm
Propagation Loss	< 0.7 dB/cm
Δn	10^{-2} - 10^{-3}

- Single mode & Multi-mode
- Bending in XYZ
- In-bulk termination and tapering
- Combination with ferrules and V-grooves
- Monolithic integration with micro-optical elements
- Alignment markers for assembly & packaging
- Facet polishing for rapid prototyping and characterization

USPs

- In-glass photonic wire-bonding
- Monolithic integration of functionalities
- Co-packaged photonic systems

ASSEMBLY & WELDING

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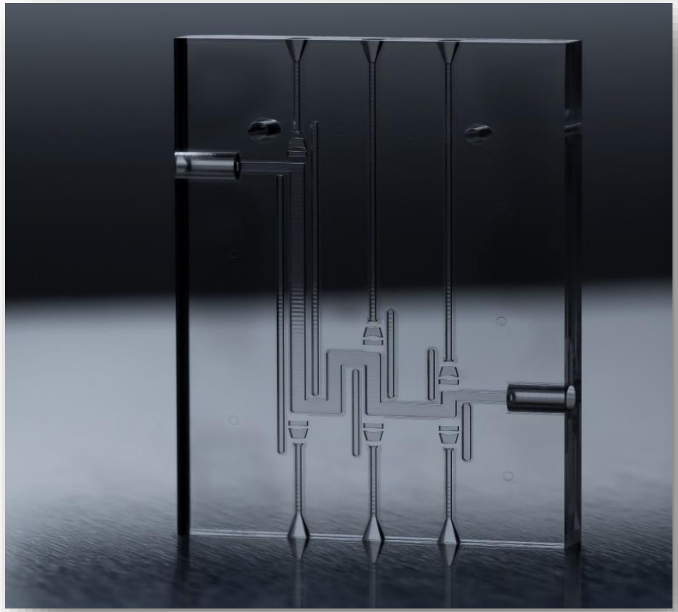
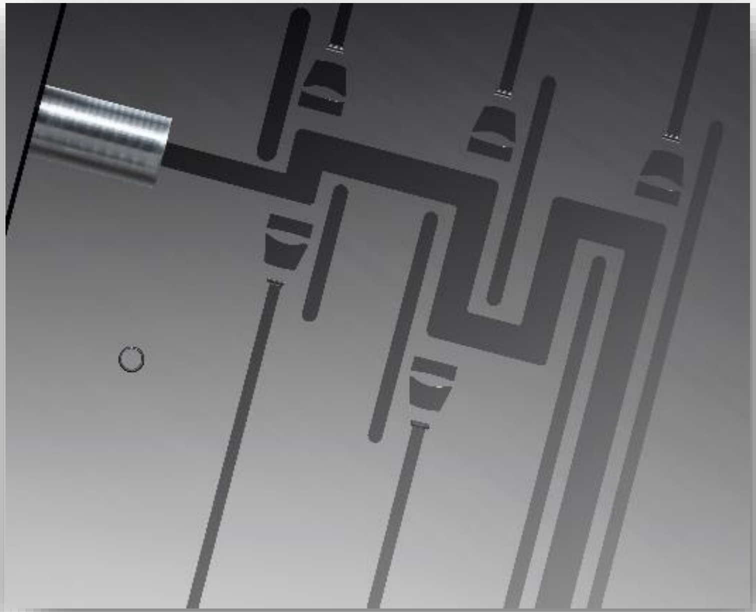
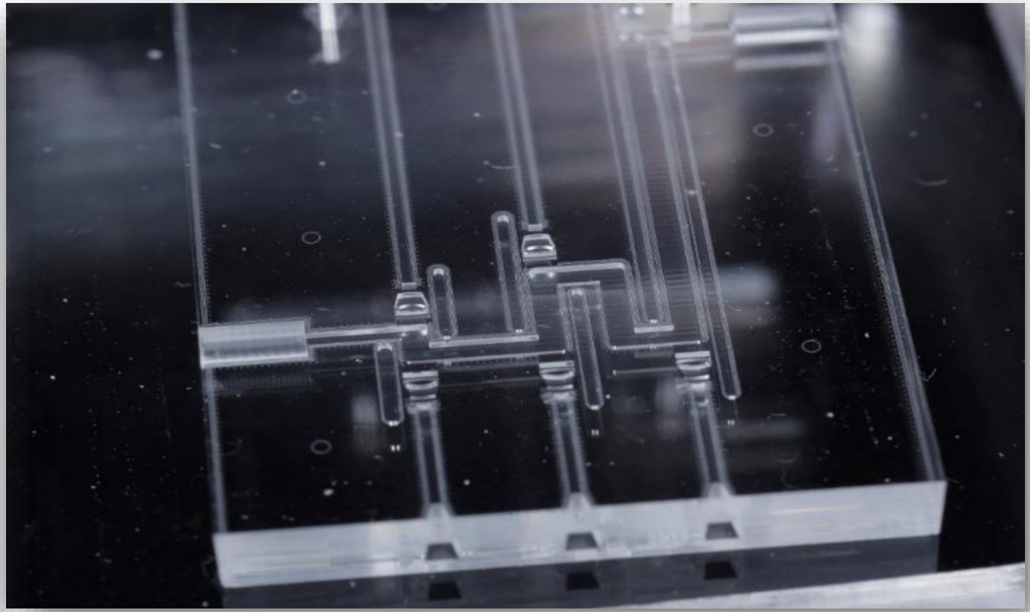






APPLICATION

- Optofluidic Photonic Lab-on-a-Chip
- Monolithically integrated micro-optical system for the optical spectroscopy in a microfluidic structure

USPs

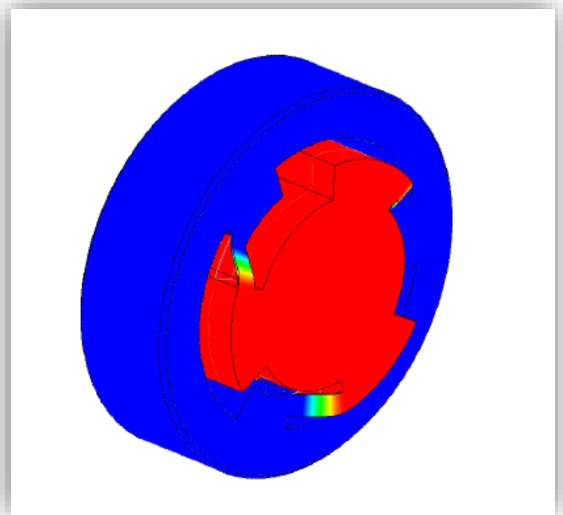
- Combination of optical & non-optical functionalities
- Monolithic integration
- Welding (glass-glass, glass-silicon, etc.)

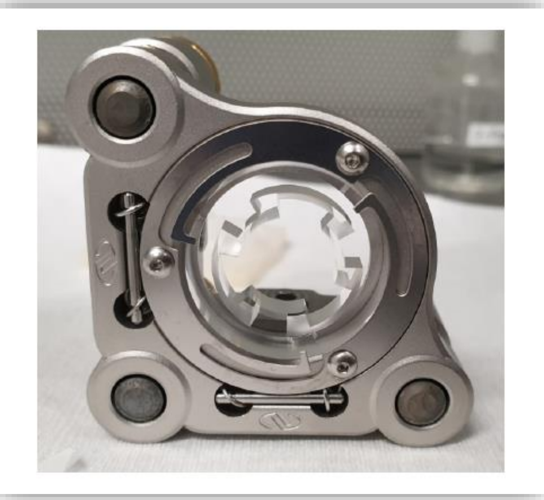
CEA, DEN, DMRC, University of Montpellier, Marcoule, France.
Elodie Mattio et al. Photonic Lab-on-a-Chip analytical systems for nuclear applications: optical performance and UV–Vis–IR material characterization after chemical exposure and gamma irradiation.
Journal of Radioanalytical and Nuclear Chemistry (2020) 323:965–973.

MONOLITHIC INTEGRATION: ex. MICRO-MECHANICS

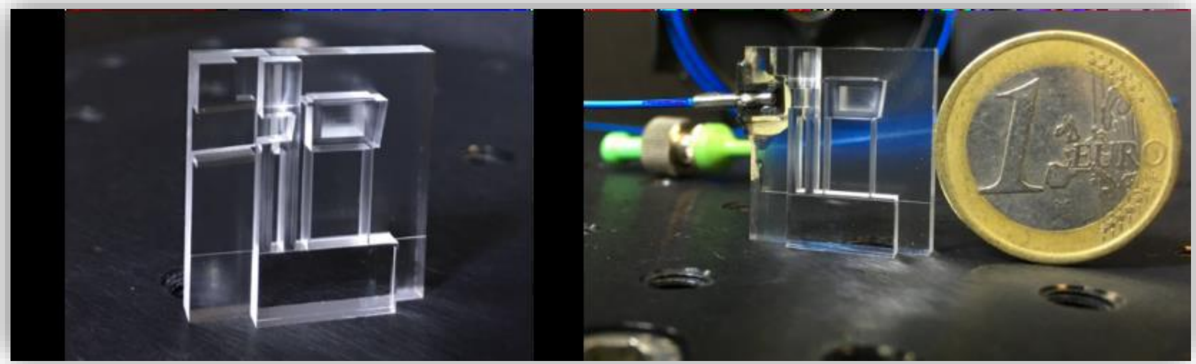
APPLICATION
- Optomechanical inertial sensor
- Comparable performance to current sensors used in gravitational wave detectors

APPLICATION
- Optomechanical accelerometer
- Tested for high sensitivity broadband acceleration measurements (mechanical oscillator quality factor $\approx 10^5$)





Jonathan Carter - A High Q, Quasi-Monolithic Optomechanical Inertial Sensor (2020)



Felipe Guzmán - Compact fully monolithic optomechanical accelerometer (2018) / https://lasso.engr.tamu.edu/

USPs
- Exploitation the elastic properties of glass flexures
- Monolithic integration of functionalities
- Introduction of alignment features

FEMTOprint for MICRO-OPTICS

FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

WHAT CAN WE DO FOR YOU?

- 3D micro-manufacturing of glass miniaturized & micro- optical components, devices, and systems
- From free-form 2.5D micro-optical elements to 3D miniaturized optical systems
- From feasibility & fast prototyping to pilot manufacturing & volume production
- Origination, Mastering & Tooling for large volume replication (UV imprint, hot embossing, injection molding)
- Monolithically integrated photonic systems, incl. fiber-to-chip coupling solutions for PICs & 3D waveguides (photonic wire bonding)

WHAT CAN YOU DO FOR US?

- Design, Metrology, Functional testing (currently)
- Requests for fast-prototyping, pilot manufacturing, and mastering/tooling services
- Collaboration on the development & manufacturing of
  - miniaturized & micro- optical components, devices, and systems
  - application specific photonic systems
  - multifunctional glass micro-systems

FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

Thank you!

OPEN POSITIONS

- *R&D Engineer in Optics*
- *Production Engineer*
- *Quality Control Manager*
- …

www.femtoprint.ch/job-offers

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