FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

# 3D printing of Glass Micro-devices for Integrated Photonics and Miniaturized Optics

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EPIC European Photonics Industry Consortium

*CMOS Compatible Integrated Photonics*
*IMEC – Leuven, September 7th-8th, 2022*

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swiss made

TÜVRheinland CERTIFIED
Management System EN ISO 13485:2016
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

FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

01 TRANSPARENT AND ISOTROPIC

02 STABLE AND ELECTRICALLY INSULATING

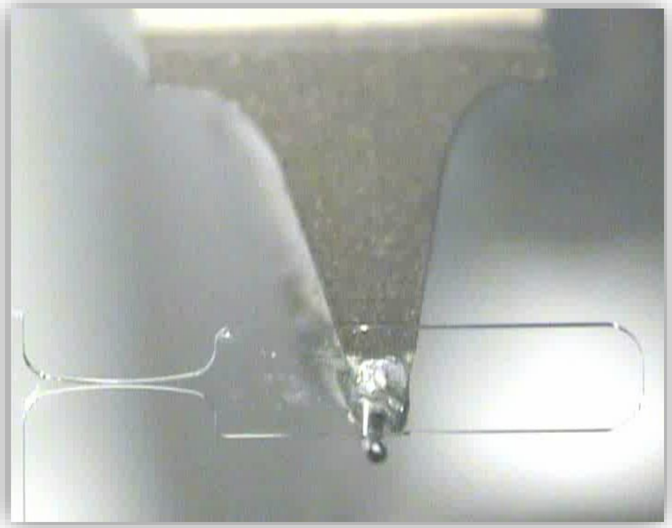
03 BIOCOMPATIBLE

04 ELEVATED THERMAL PROPERTIES

05 HIGHLY ELASTIC

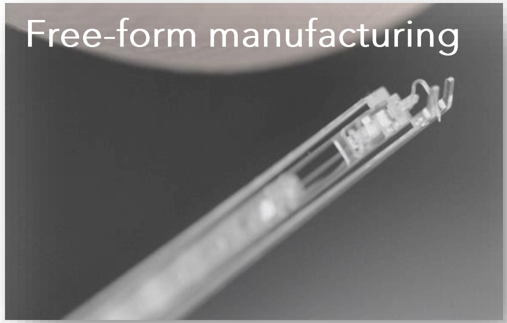
06 RESISTANT TO CORROSION, ABRASION AND SCRATCHES

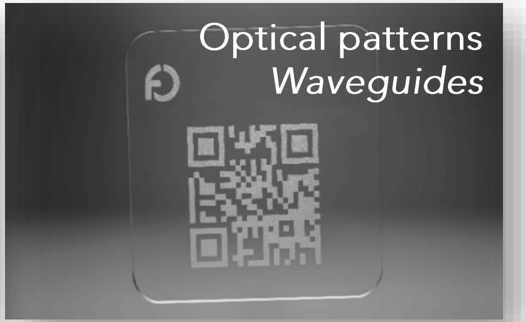
07 NEUTRAL TO MAGNETIC FIELDS

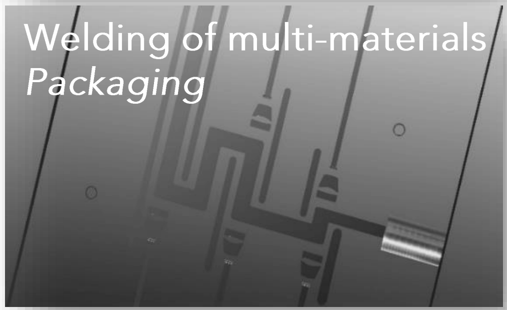


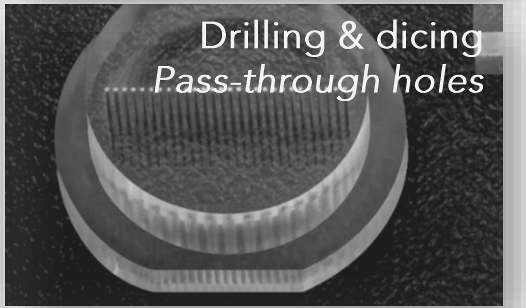
# 3D PRINTING OF GLASS MICRO-DEVICES

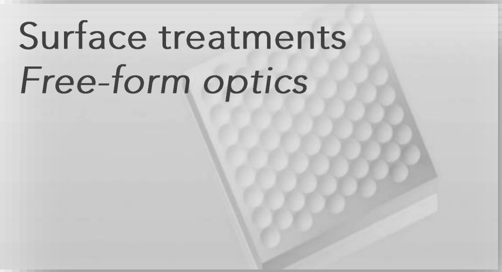
## CAPABILITIES

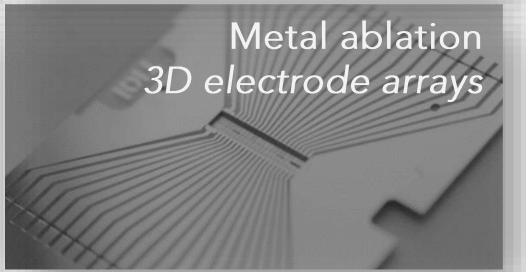


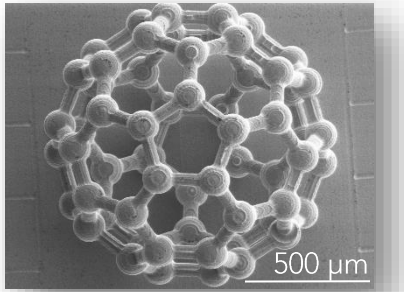




## PERFORMANCES*

*in SiO2

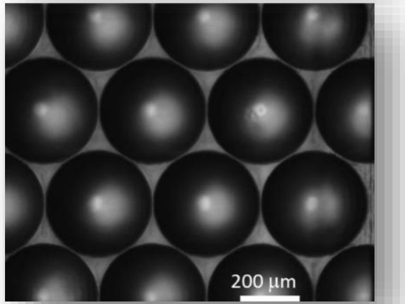
**RESOLUTION AND TOLERANCES**

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



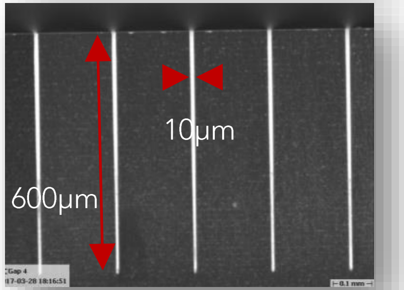

**SURFACE QUALITY**

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




**ASPECT RATIO**

- Channel aspect ratio ≥ 1:500
- Bulk height up to 30 mm
- Working area up to 300 mm Ø



# MICRO-MANUFACTURING AT WAFER-LEVEL

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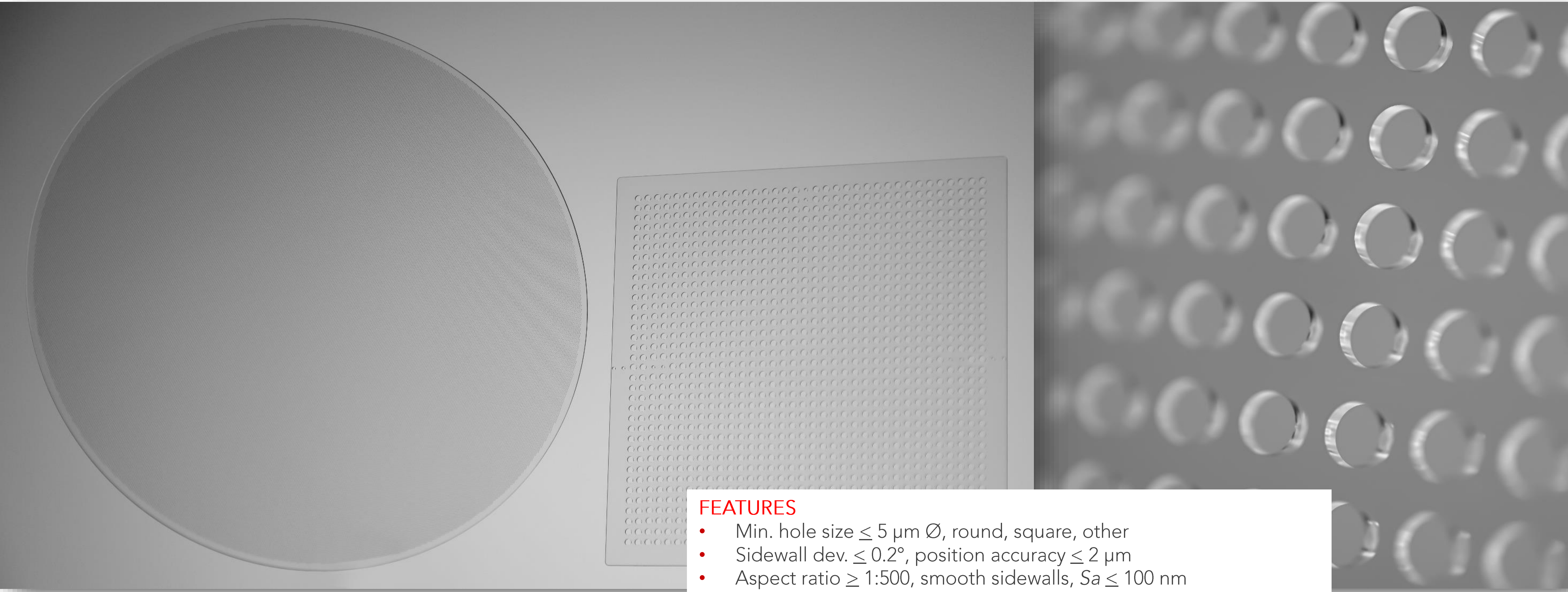
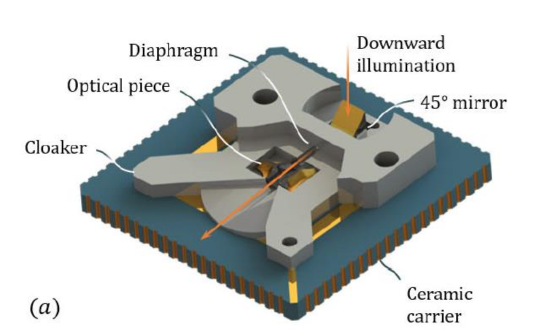


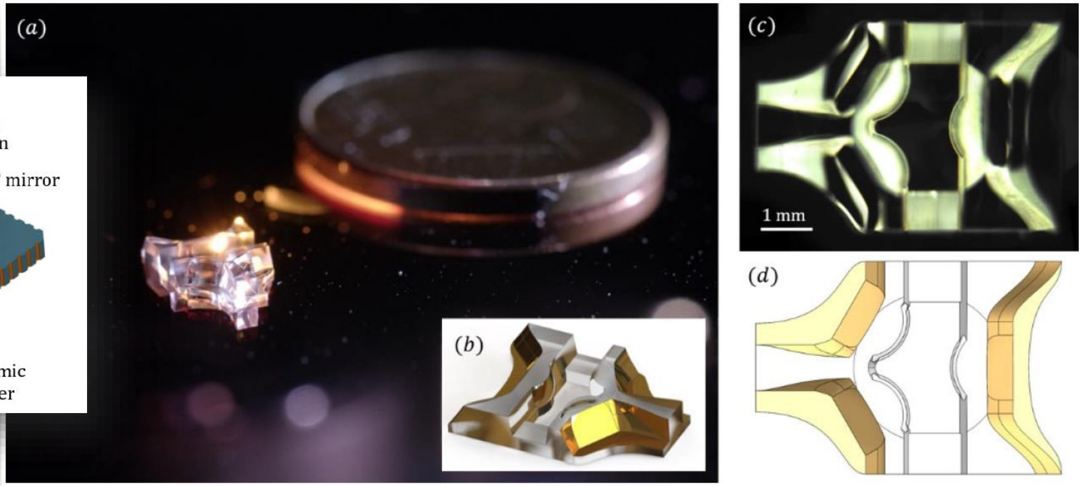
FEATURES
- Min. hole size ≤ 5 µm Ø, round, square, other
- Sidewall dev. ≤ 0.2°, position accuracy ≤ 2 µm
- Aspect ratio ≥ 1:500, smooth sidewalls, *Sa* ≤ 100 nm
- Sharp or tapered edge, no sagging and chipping

# CO-PACKAGED MINIATURIZED OPTICS

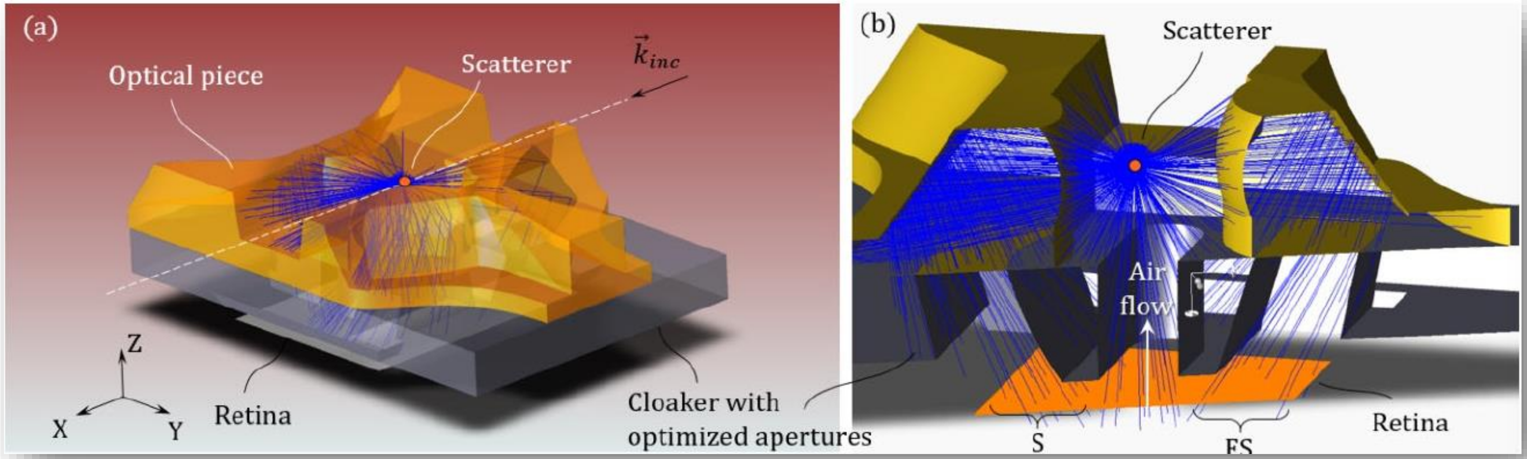
APPLICATION
- Air quality monitoring
- Improved sensitivity by the integration of a miniaturized refractive/reflective optical system

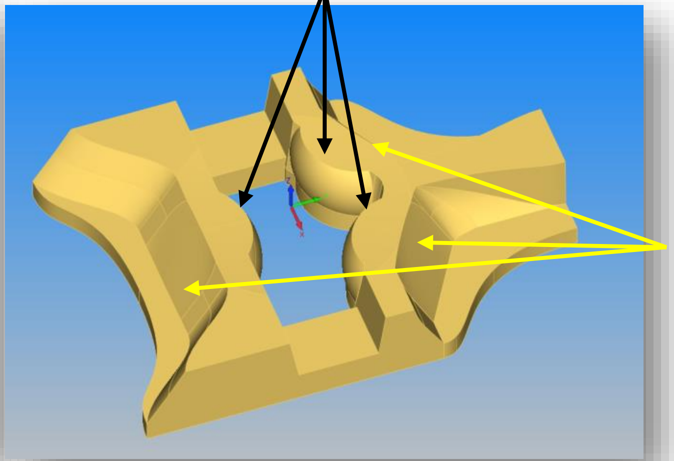
USPs
- Monolithic integration of optical functions
- Free-form fabrication in 3D
- Co-packaged miniaturized optics




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

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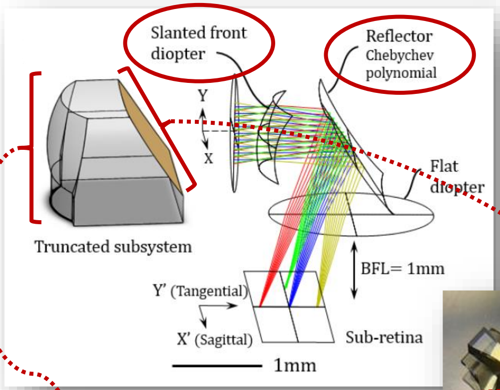
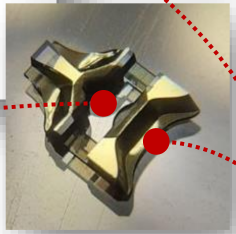
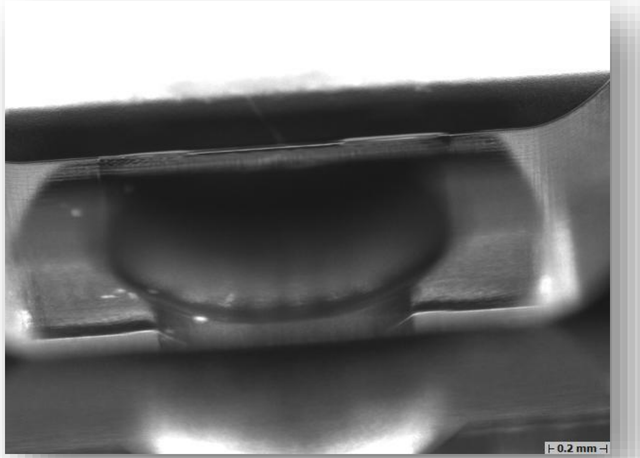
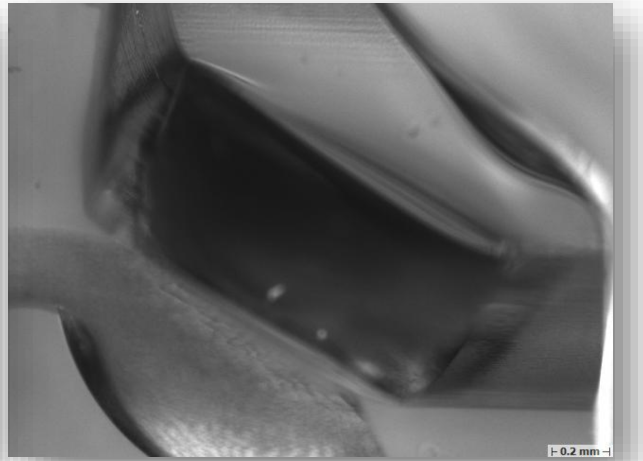


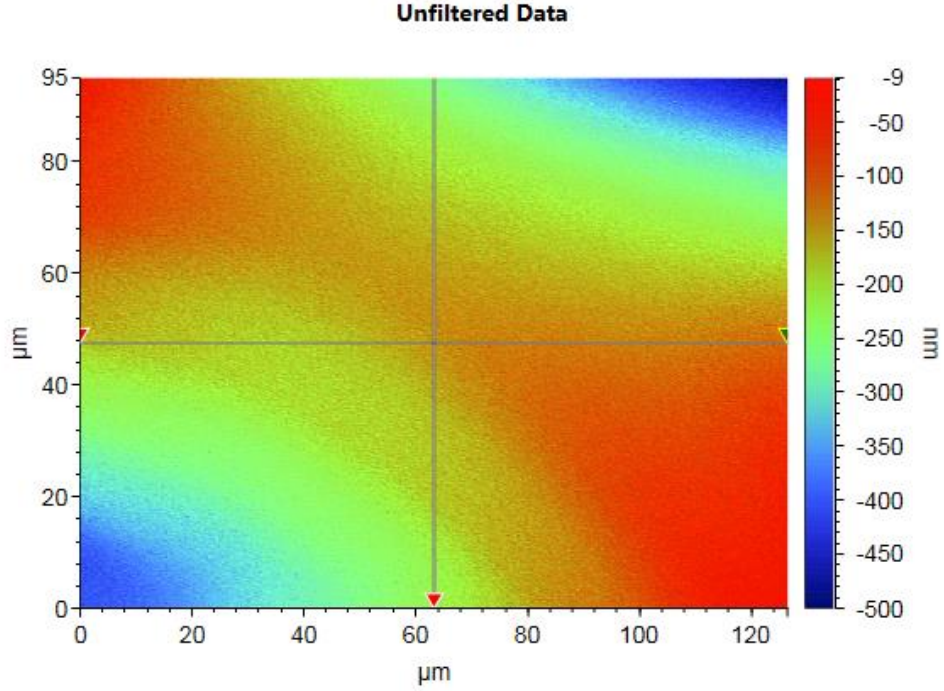
Slanted diopter




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.*

# MINIATURE OPTICAL PARTICLE COUNTER & ANALYZER

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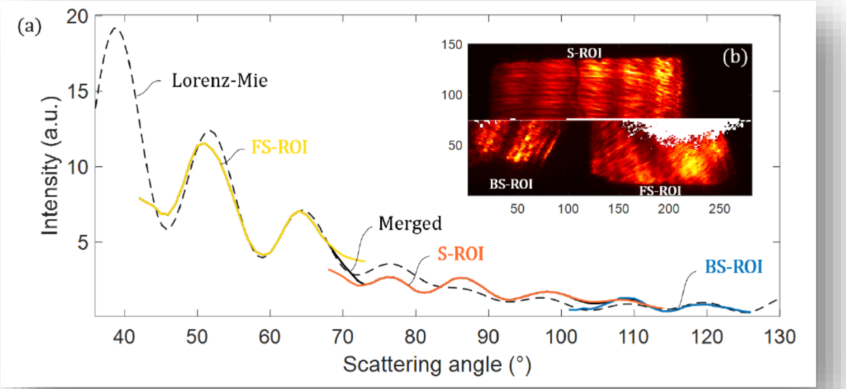
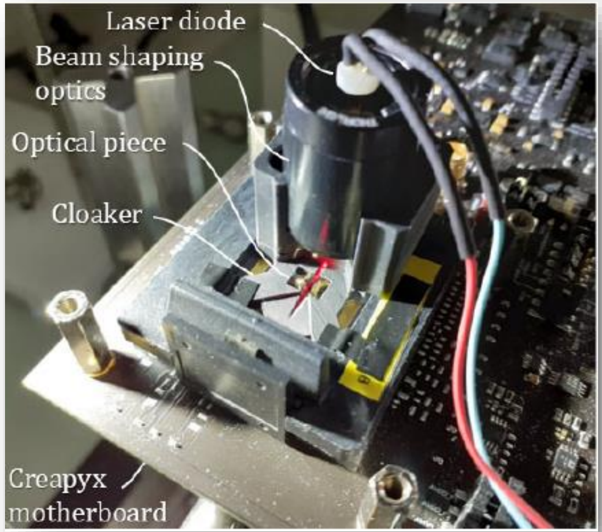
## Functional Testing




*Measured scattering signature reproduces well the theoretical model*




## Advantages

- Increased scattering flux collection
- Insensitivity to particle position
- Ultra-wide field of view
- Simplified image processing
- Real time monitoring
- Reduced costs
  - No reagents
  - No expensive instrumentation needed
  - Reusable several times

## Possible future applications

- Identification of biochemicals
- Clinical diagnostics

*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.*

# MICRO-OPTICS

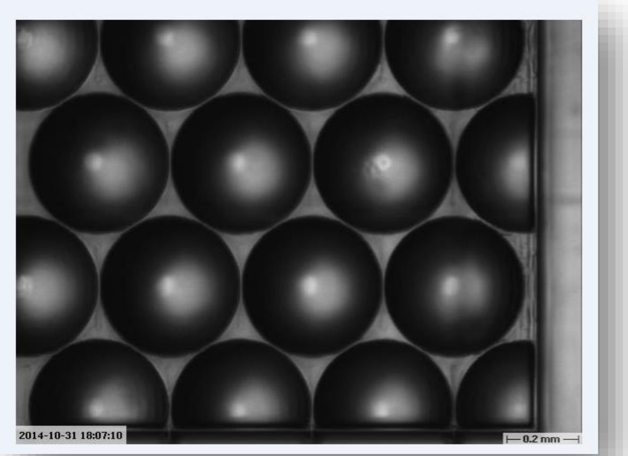


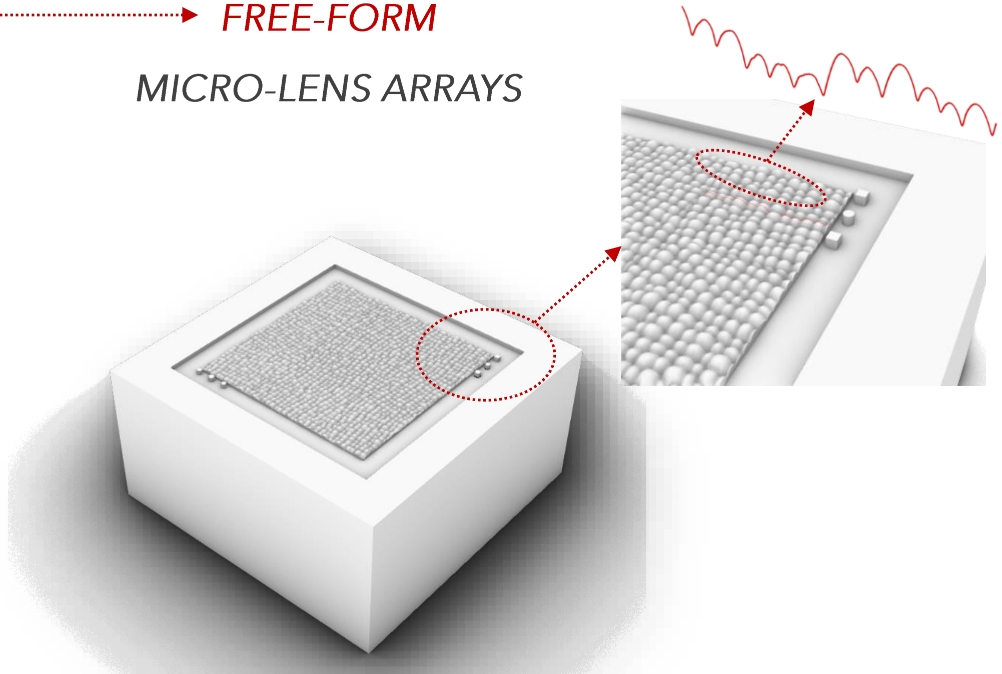
*SPHERICAL or ASPHERICAL* → *NON-SPHERICAL* → *FREE-FORM*

*MICRO-LENSES*
*&*
*MICRO-LENS ARRAYS*

*MICRO-OPTICAL ELEMENTS*

*MICRO-LENS ARRAYS*



*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 – (A)SPHERICAL MICRO-LENS ARRAYS

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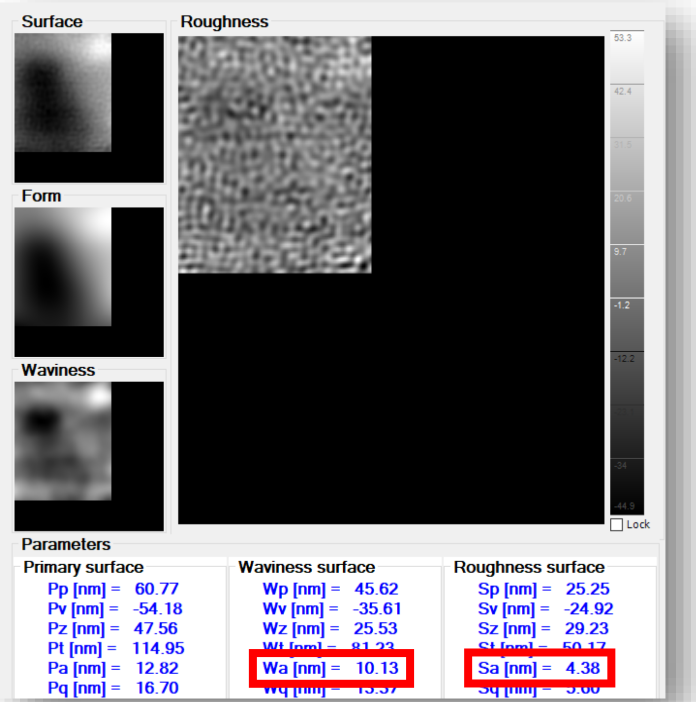
## Flat surfaces

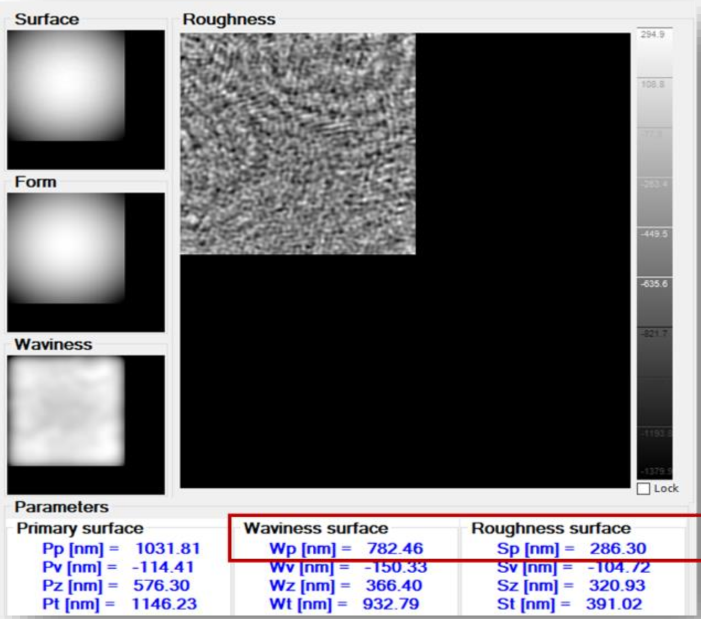
- *Sa* < 10 nm

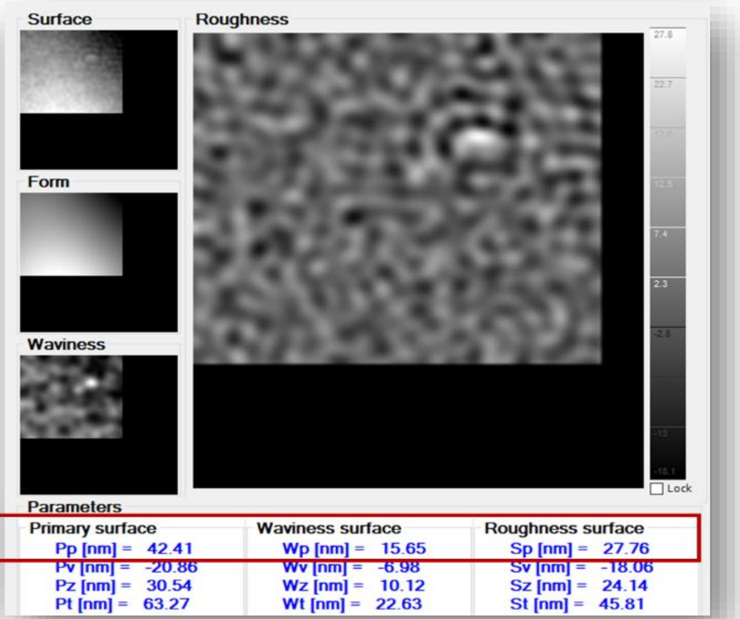



## Spherical / Aspherical Micro-lenses

(RoC = 125 µm, SAG = 100 µm)

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




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

# MICRO-OPTICS – FREE-FORM MICRO-LENS ARRAYS

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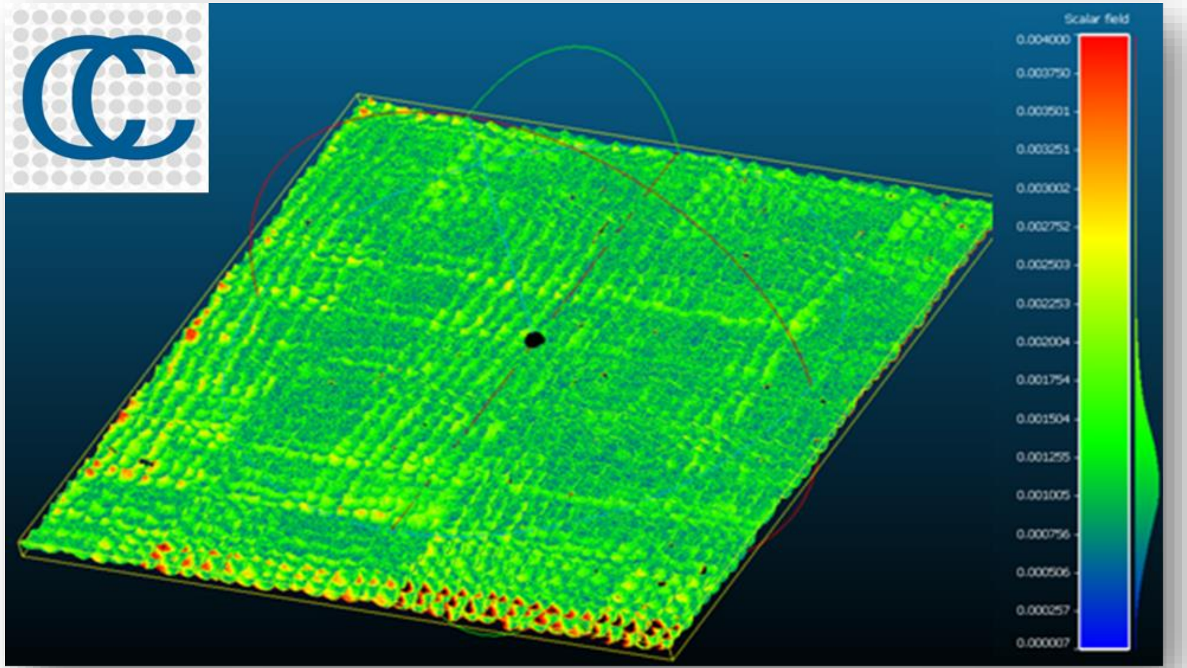
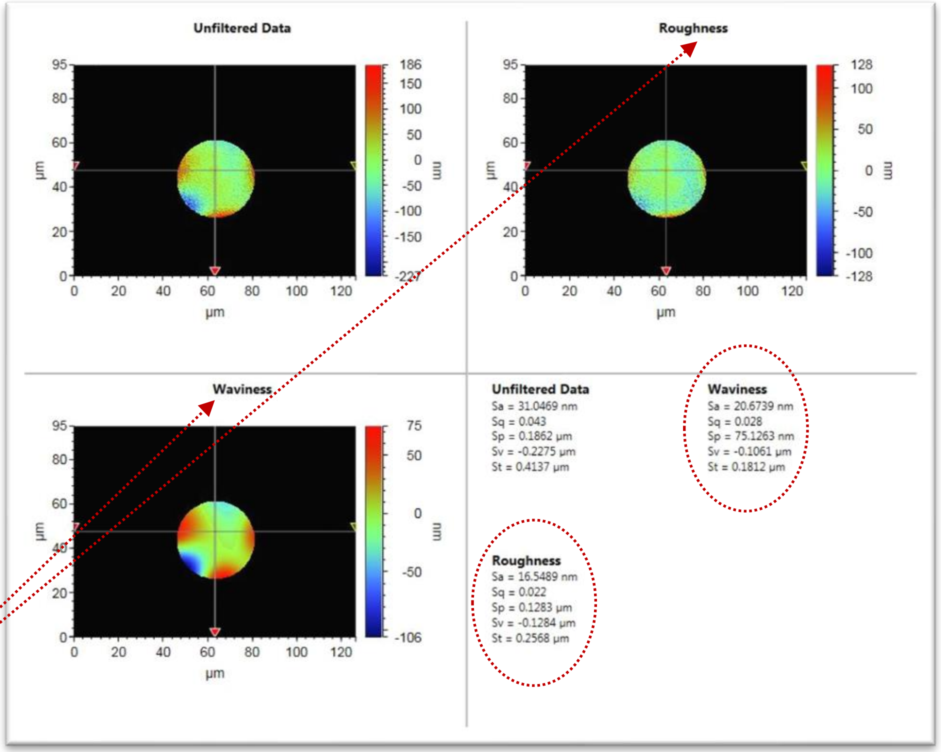
## Free-form Micro-lenses

(SAG = 75 µm)

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




*Nominal design vs measured surface – Cloud Compare* *Courtesy of CSEM*




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

# ASSEMBLY & PASSIVE ALIGNMENT

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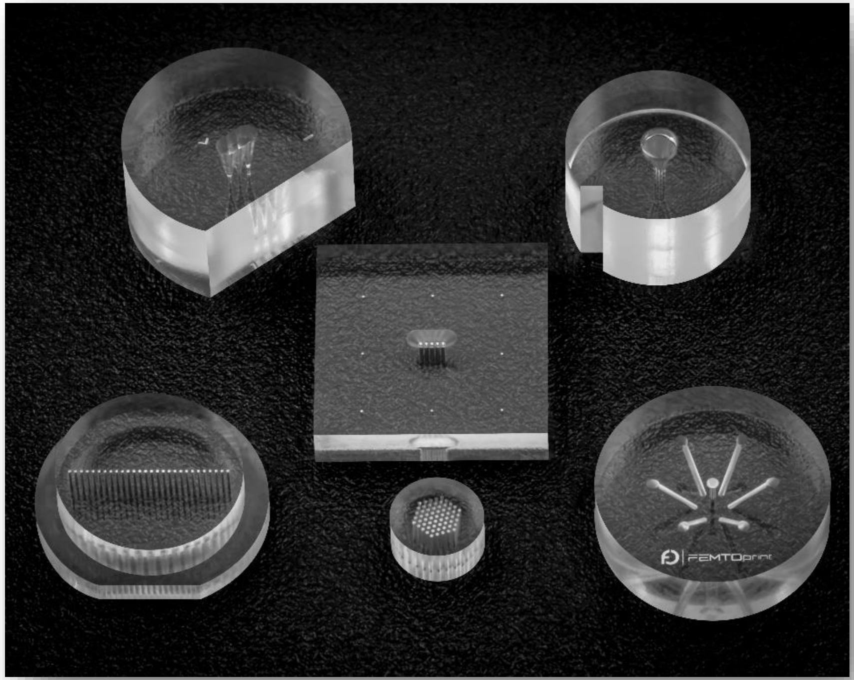
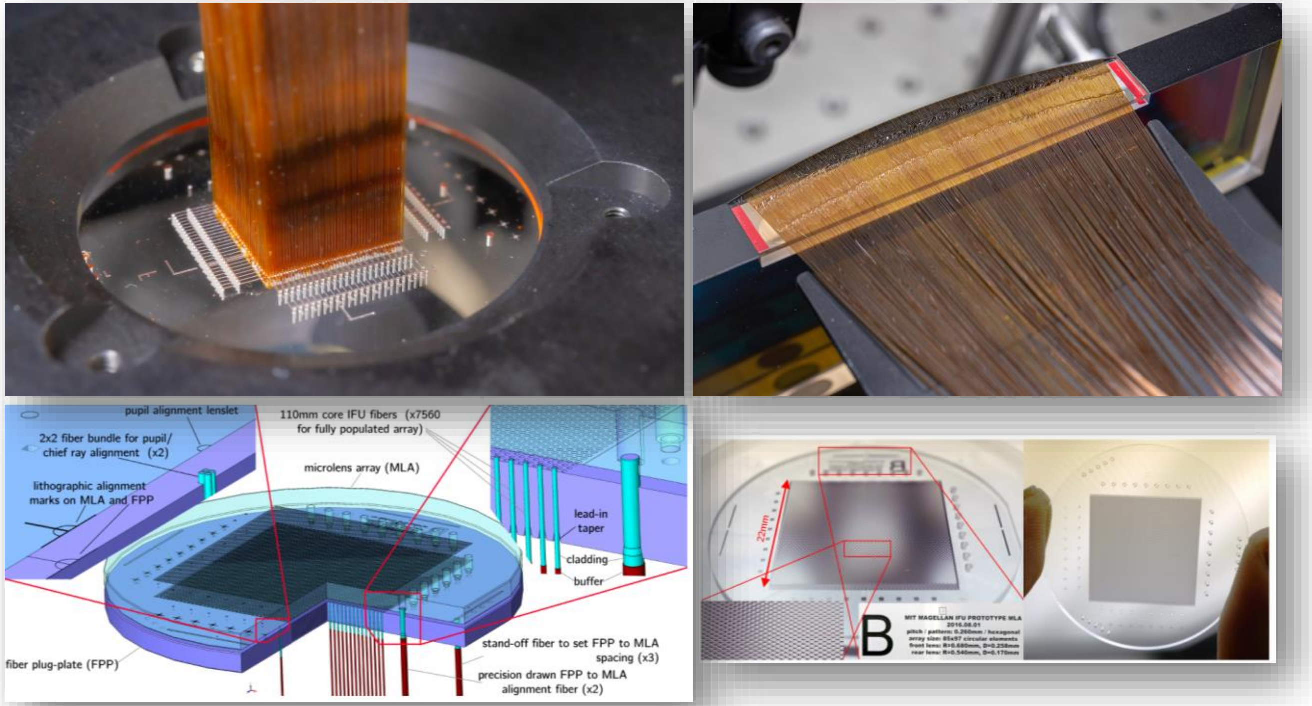
### APPLICATION

- 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



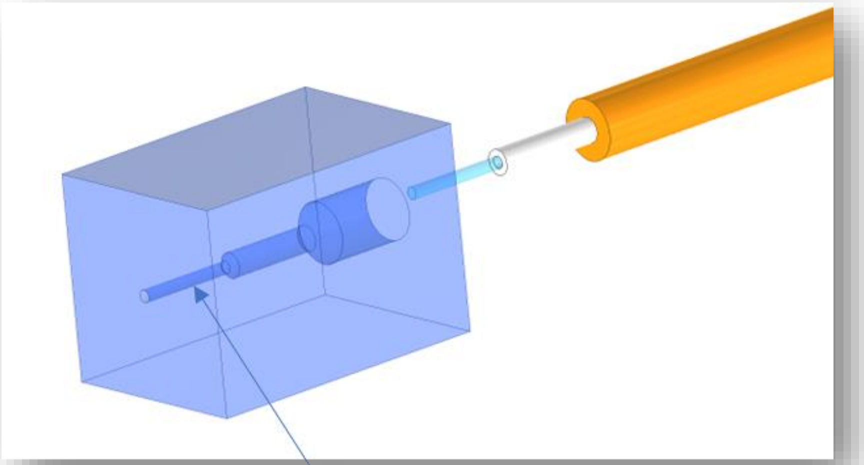

*Courtesy of Gábor Fûrész, MIT Kavli Institute for Astrophysics and Space Research*

### USPs

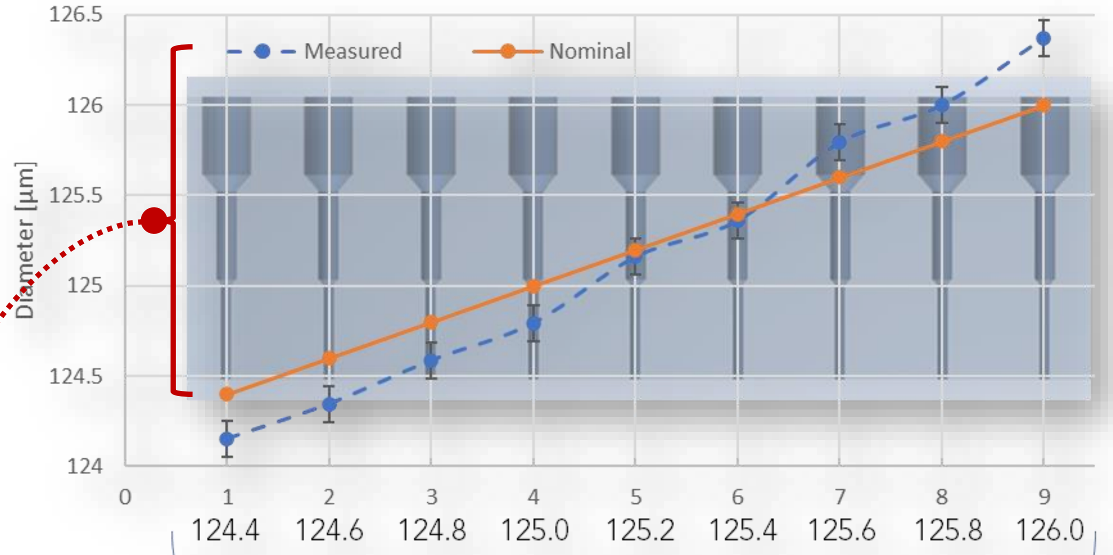
- Thin to thick glass ferrules: mechanical stability & flatness
- Customized hole arrays & additional assembly features
- Precision in hole diameter and positioning < 1 µm

# FIBER FERRULES: SUB-µm CONTROL ON HOLE DIAMETER

- 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



Guiding section (length > 1.5 mm)

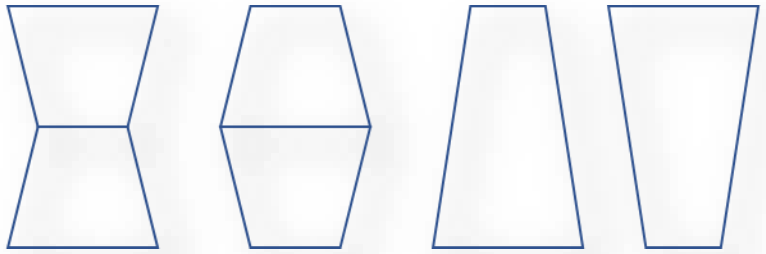



Nominal target diameters for the guiding holes [µm]

The mechanical measurements confirm that

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

# FIBER FERRULES: SUB-° CONTROL ON HOLE CYLINDRICITY



- Mechanical measurements ➔ minimum diameter over the hole length
- The hole shape can vary

- Optical measurements to verify angular misalignment & conicity of the holes

The optical measurements did not reveal any diameter difference along single holes

**Error on hole cylindricty < 0.1°**

# FIBER FERRULES: REPEATIBILITY

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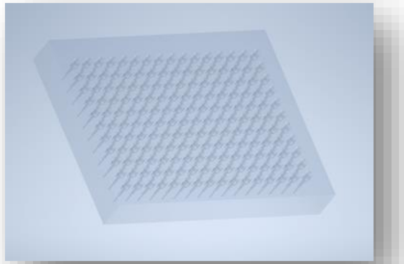
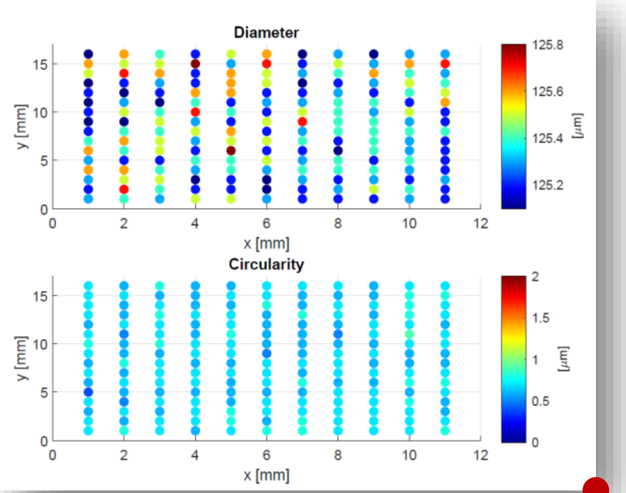
- 2D array of 11 x 16 holes
  - Target hole diameter = 125.5 µm
  - Inter-hole nominal distance (x,y) = 1mm

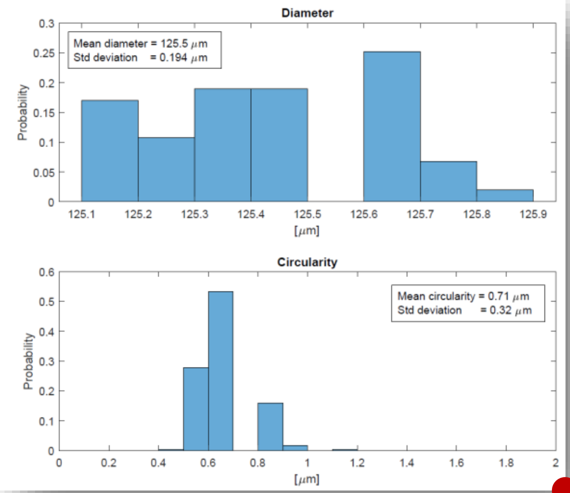


- 3x identical 2D arrays




➢ Diameter: narrow distribution around the target value

➢ Circularity: better than the microscope resolution (± 2 µm)




*Resolution of the diameter measurement = accuracy of the pin gauges, i.e. 0.1 µm*

➢ Average diameter on target

➢ Standard deviation < 0.2 µm

➢ Circularity better than the microscope resolution (± 2 µm)

Hole homogeneity verified on a single array

Repeatibility verified on multiple arrays

# PHOTONIC WIRE BONDING

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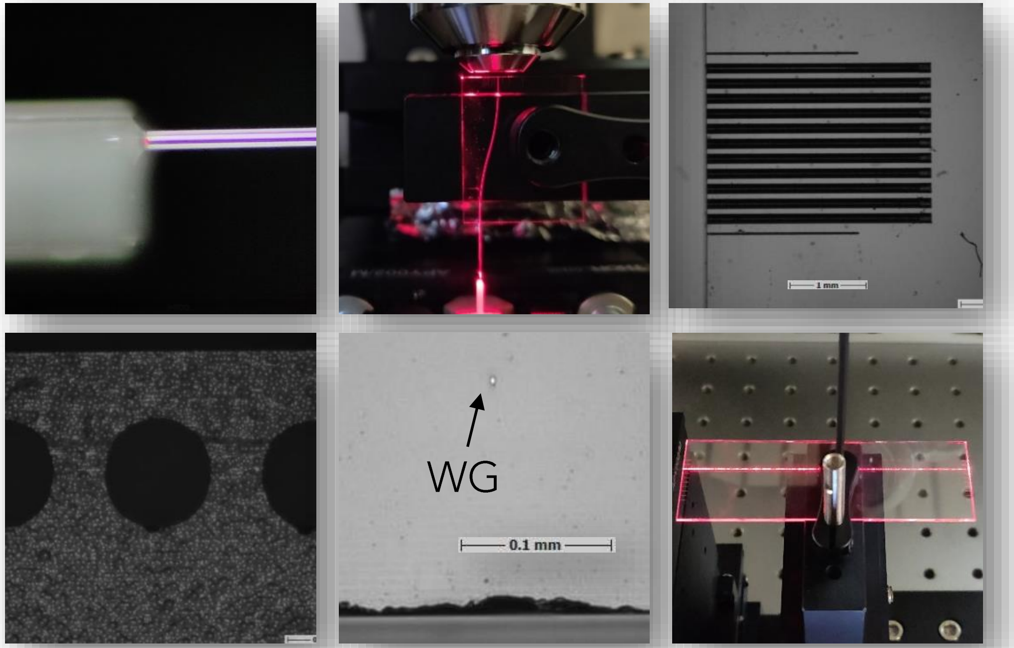


| | |
|---|---|
| Materials | FS, BF33, EXG |
| Working λ [nm] | 630, 980, 1310, 1550 |
| MFD SM [μm] | 3 to 9 |
| Relative positioning | < ± 1 μm |
| Min. Bending Radius | ≈ 25 mm |
| Propagation Loss | < 0.7 dB/cm |
| Δn | $10^{-2}$ - $10^{-3}$ |

FEATURES

- Single mode & Multi-mode
- Bending in XYZ
- In-bulk termination possible
- Alignment markers and grooves can be conveniently added
- 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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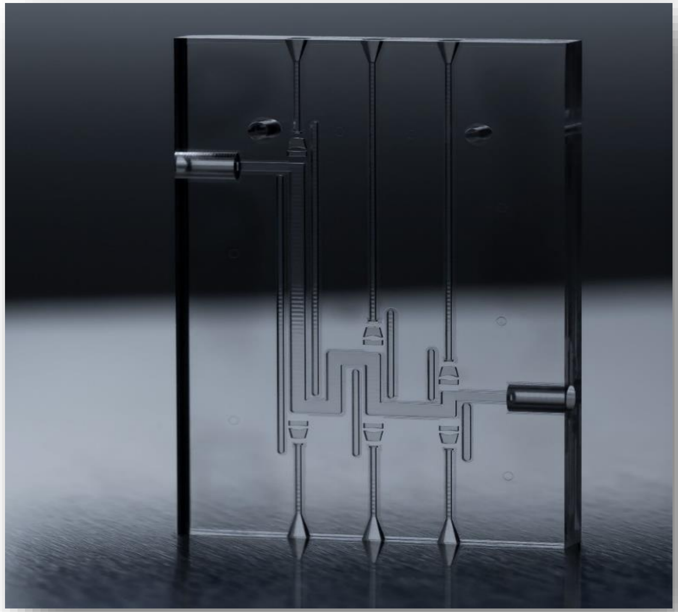

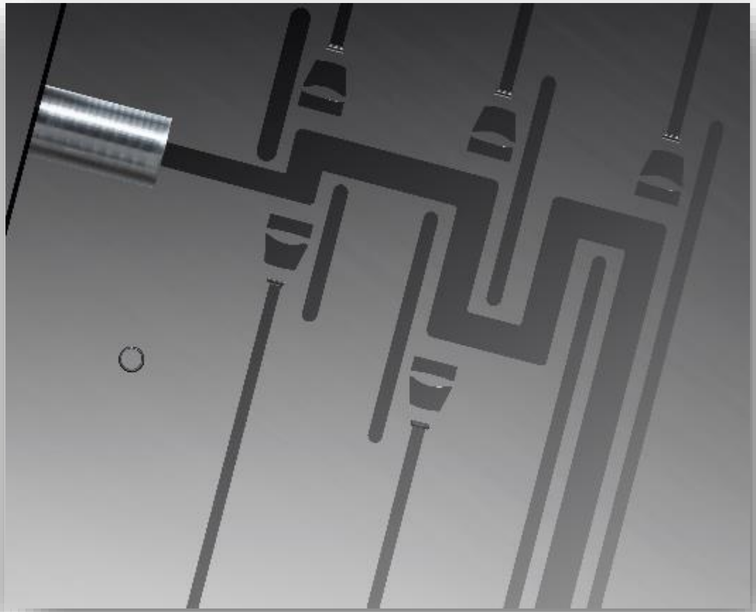

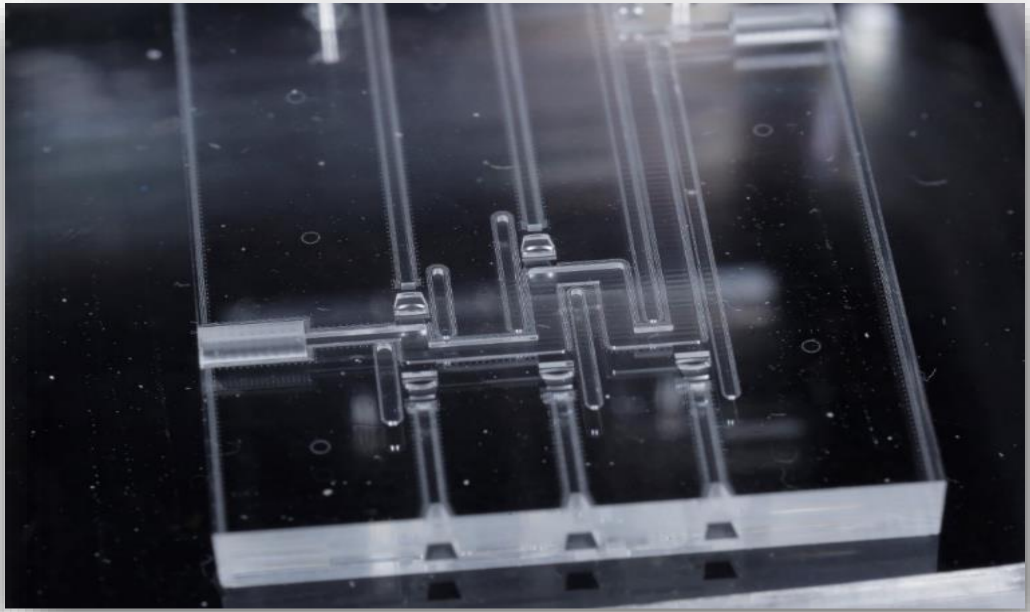

APPLICATION

- 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: MICRO-MECHANICS

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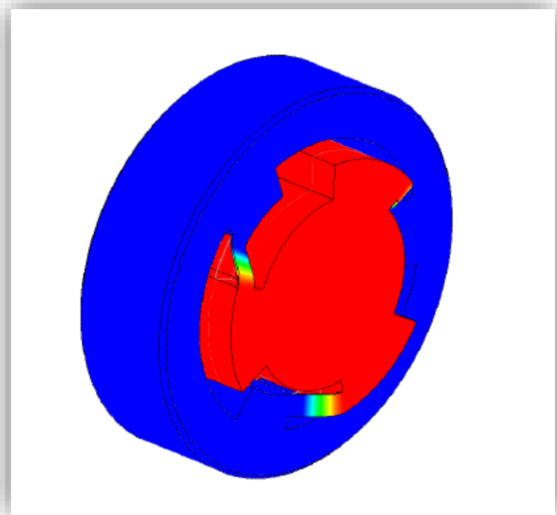
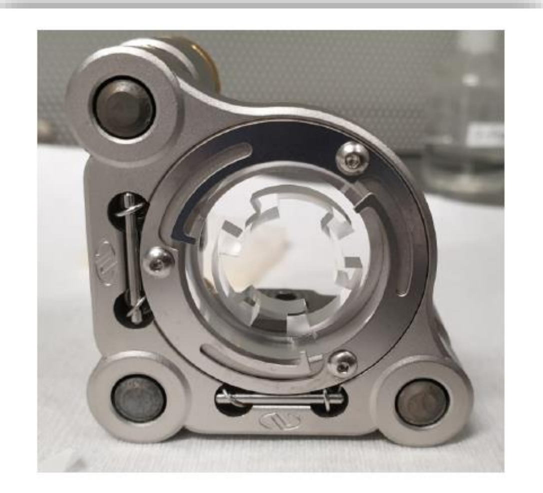
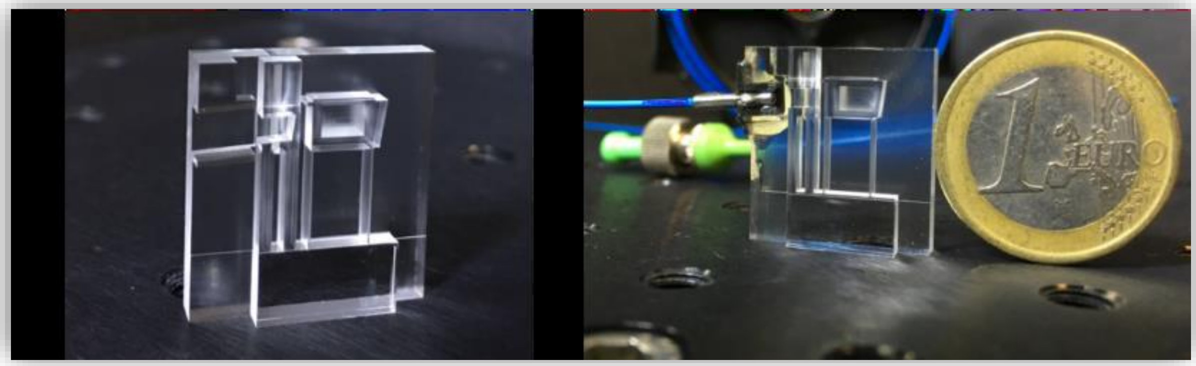
APPLICATION
- Optomechanical inertial sensor
- Comparable performance to current sensors used in gravitational wave detectors





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

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




*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

# MONOLITHIC INTEGRATION: ELECTRICAL FUNCTIONALITIES

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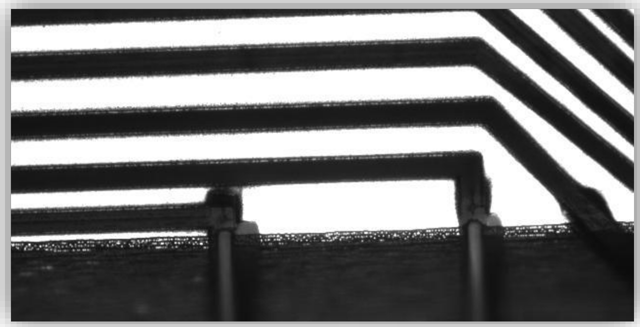
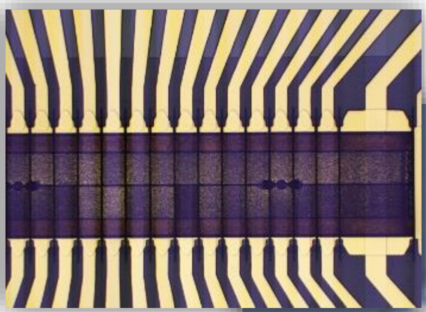
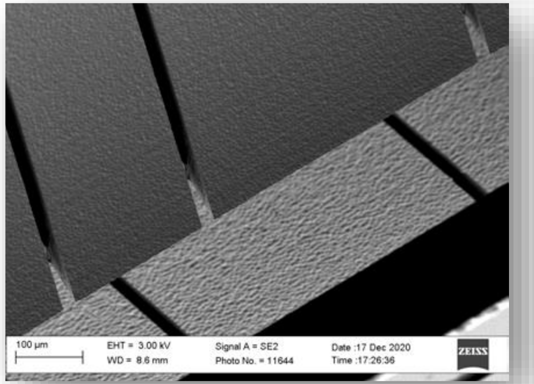
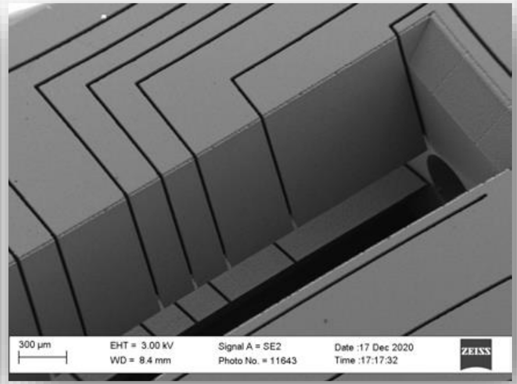
APPLICATION

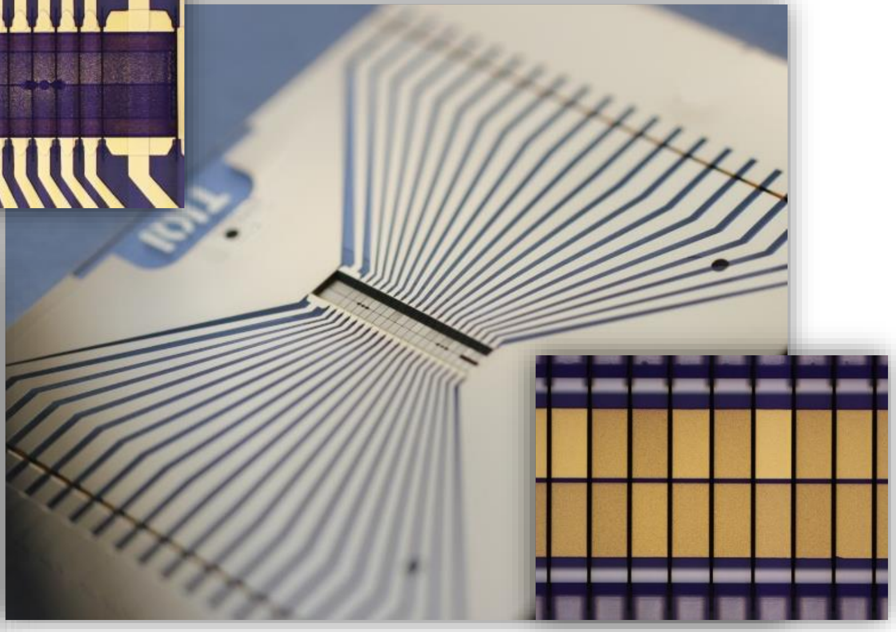
- Laser ablation of thin metal films
- Ion traps for quantum computing







Courtesy of ETH Zürich

## USPs

- Laser ablation of different thin metallic layers: ITO, Cr-AU, Ti-Pt
- Electrode isolation on both flat & free-form surfaces (down to few µm's)
- Integration of electrical functionalities

# FEMTOprint for INTEGRATED PHOTONICS

FEMTOPRINT®
3D PRINTING FOR GLASS MICRODEVICES

## WHAT CAN WE DO FOR YOU?

- 3D printing of monolithically integrated glass micro-devices: from feasibility & fast prototyping to pilot & volume production
- Combine dedicated know-how in optics & photonics with full control over fabrication processes and production systems
- Provide solutions for integrated photonics, notably PICs:
  - Co-packaged miniaturized optics and micro-optics
  - In-glass photonic wire-bonding
  - High precision 1D & 2D fiber arrays (e.g. for passive alignment)
  - Packaging & assembly (incl. welding)
  - Integration of mechanical & electrical functionalities

## 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

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**9 OPEN JOB POSITIONS**

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

www.femtoprint.ch/job-offers

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