3D printing and two photon polymerization: toward the rapid prototyping of micro- nano-devices

Valentina Bertana

Chilab @ Politecnico di Torino (Department of Applied Science and Technology)

It-fab Italian Network for Micro and Nano Fabrication

NanoInnovation 2020 Rome, 15-18 September Conference & Exhibition
School on nanotechnologies

17th September 2020

3D printing and two photon polymerization: toward the rapid prototyping of micro- nano- devices

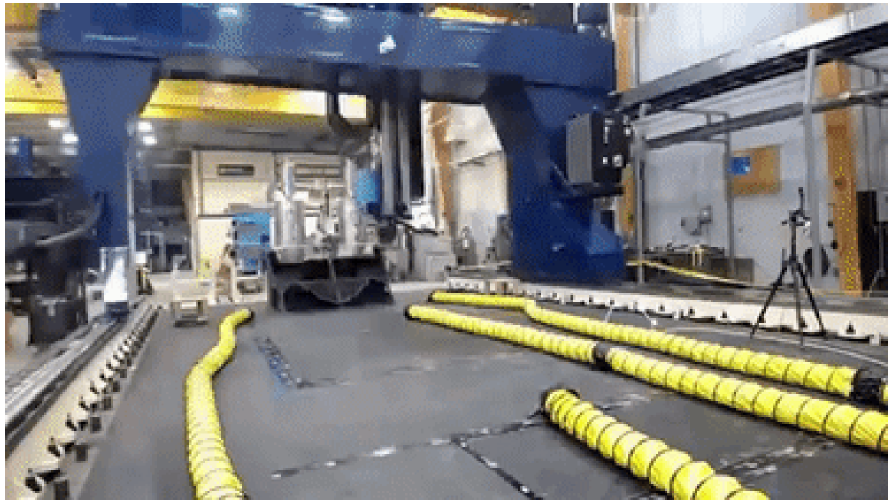
From big...

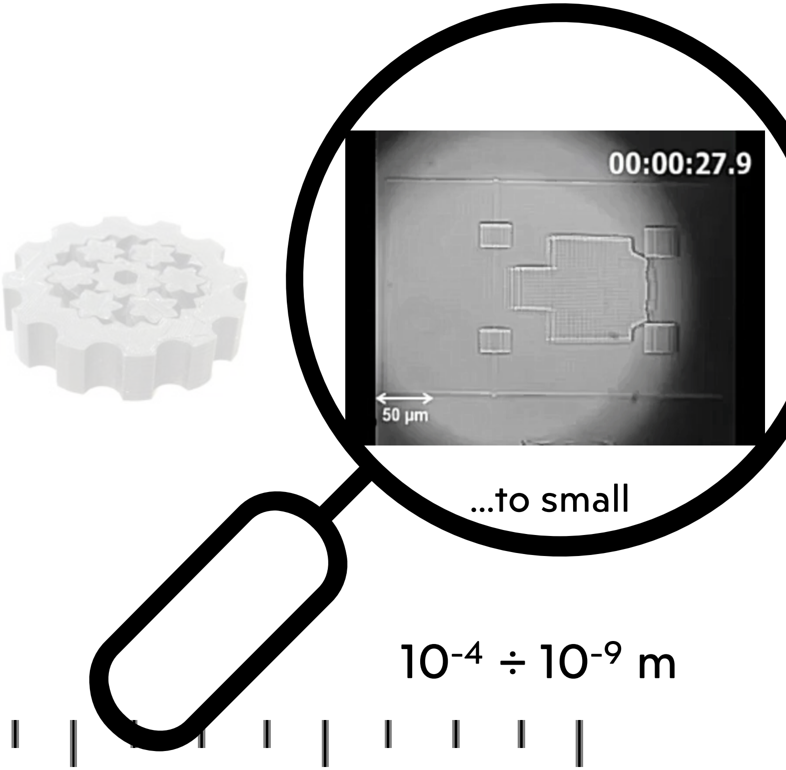
...to small

10^{2} m

$10^{-4} \div 10^{-9}$ m

3D printing and two photon polymerization: toward the rapid prototyping of micro- nano- devices





From big...

10^2 m

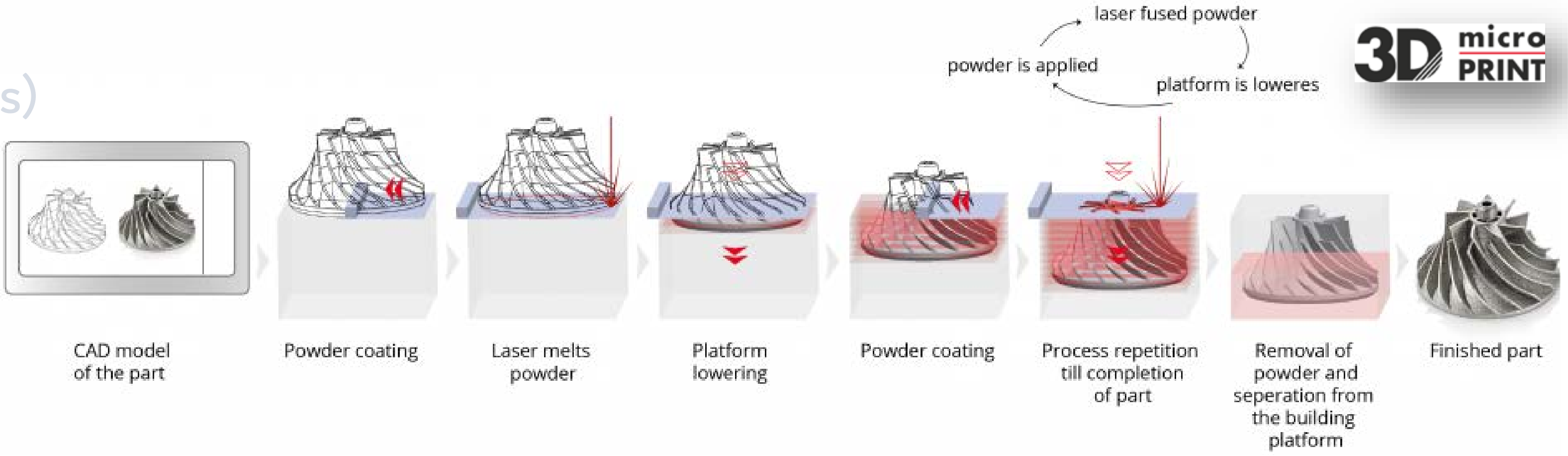
$10^{-4} \div 10^{-9}$ m

- Micro laser sintering (metals)
- Micro electrochemical deposition (metals)
- Microstereolithography (polymers)
- Two photon polymerization (polymers)

10^2 m

$10^{-4} \div 10^{-9}$ m

- Micro laser sintering (metals)
- Micro electrochemical deposition (metals)
- Microstereolithography (polymers)
- Two photon polymerization (polymers)



Infrared LASER

LASER spot size ≤ 15 μm

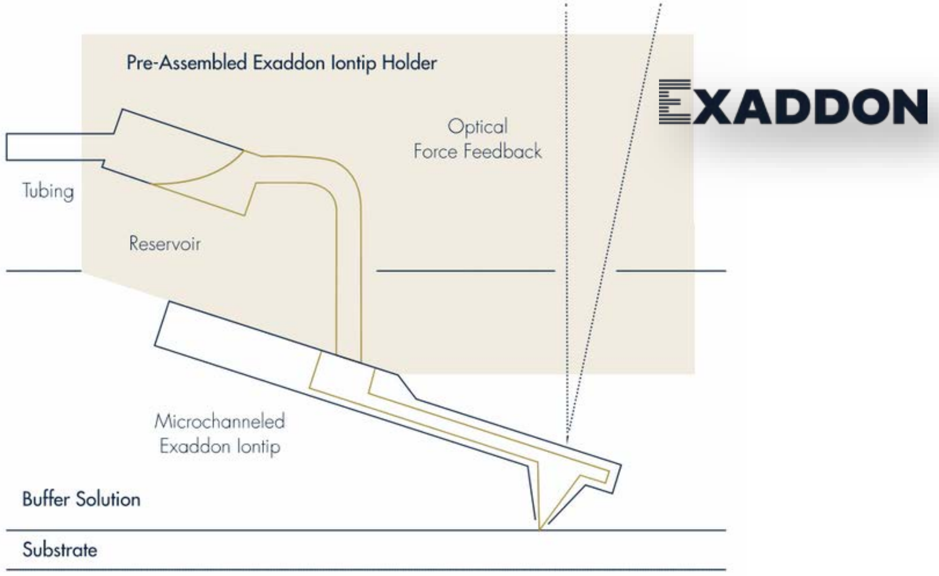
Layer thickness 1÷5 μm

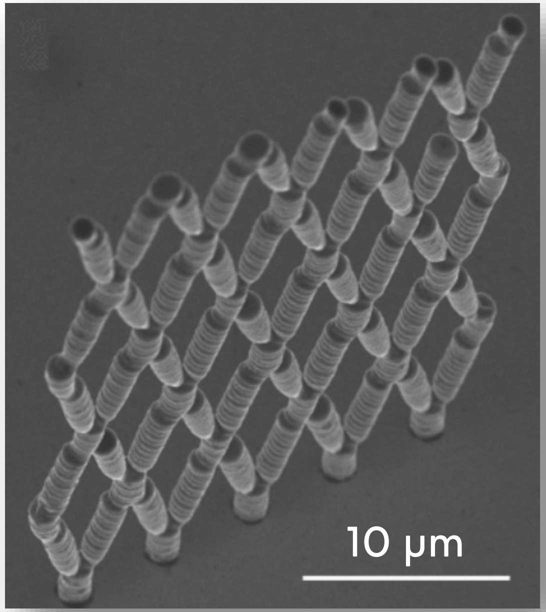
Powders (stainless steel) particle size≤ 5 μm

10^2 m

$10^{-4} \div 10^{-9}$ m

- Micro laser sintering (metals)
- **Micro electrochemical deposition (metals)**
- Microstereolithography (polymers)
- Two photon polymerization (polymers)





Interconnected truss structure of solid Cu wires

Lin, Y.-P., Zhang, Y., Yu, M.-F., *Adv. Mater. Technol.* 2019, 4, 1800393. https://doi.org/10.1002/admt.201800393

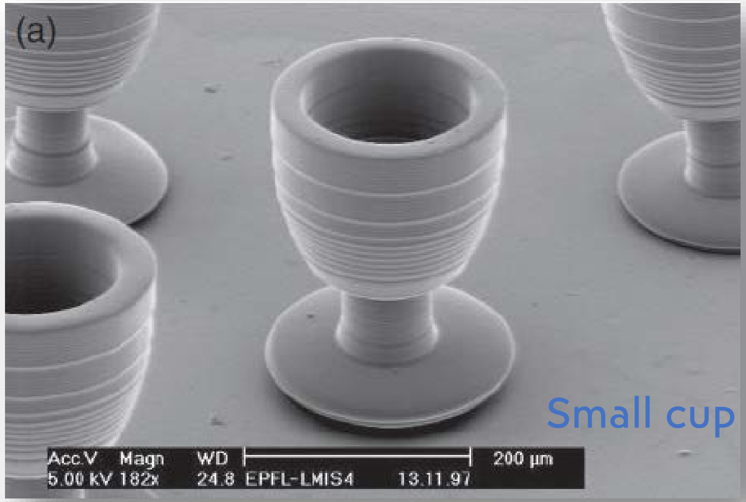
Iontip deposits metal ions

Liquid flow ~ 10^{-15} l/s

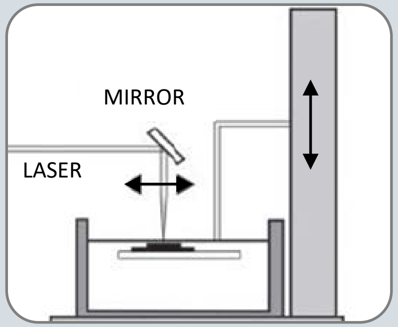
10^{2} m

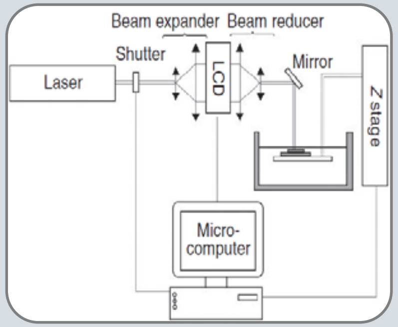
$10^{-4} \div 10^{-9}$ m

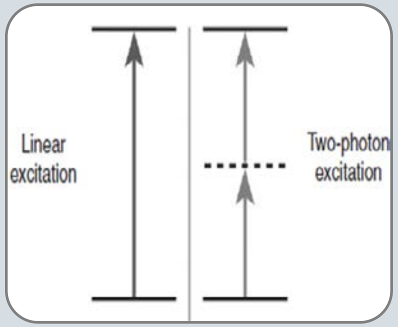
- Micro laser sintering (metals)
- Micro electrochemical deposition (metals)
- **Microstereolithography (polymers)**
- Two photon polymerization (polymers)



Three dimensional microfabrication, Baldacchini





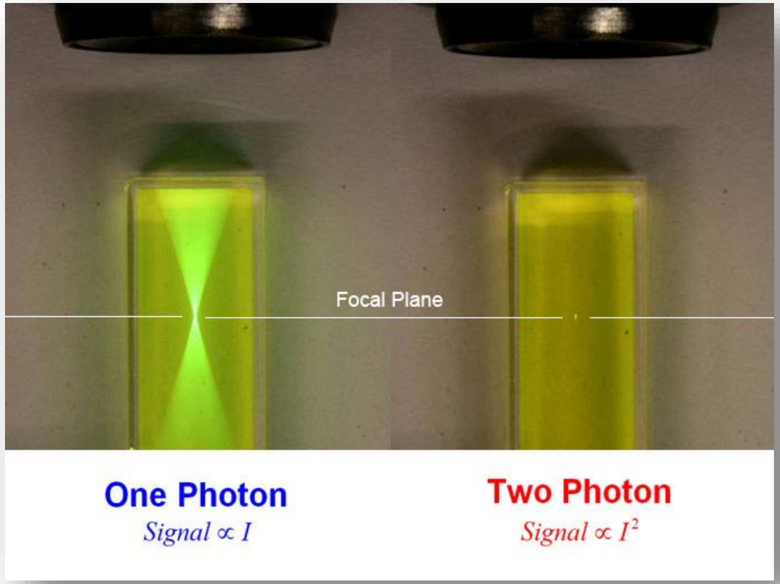


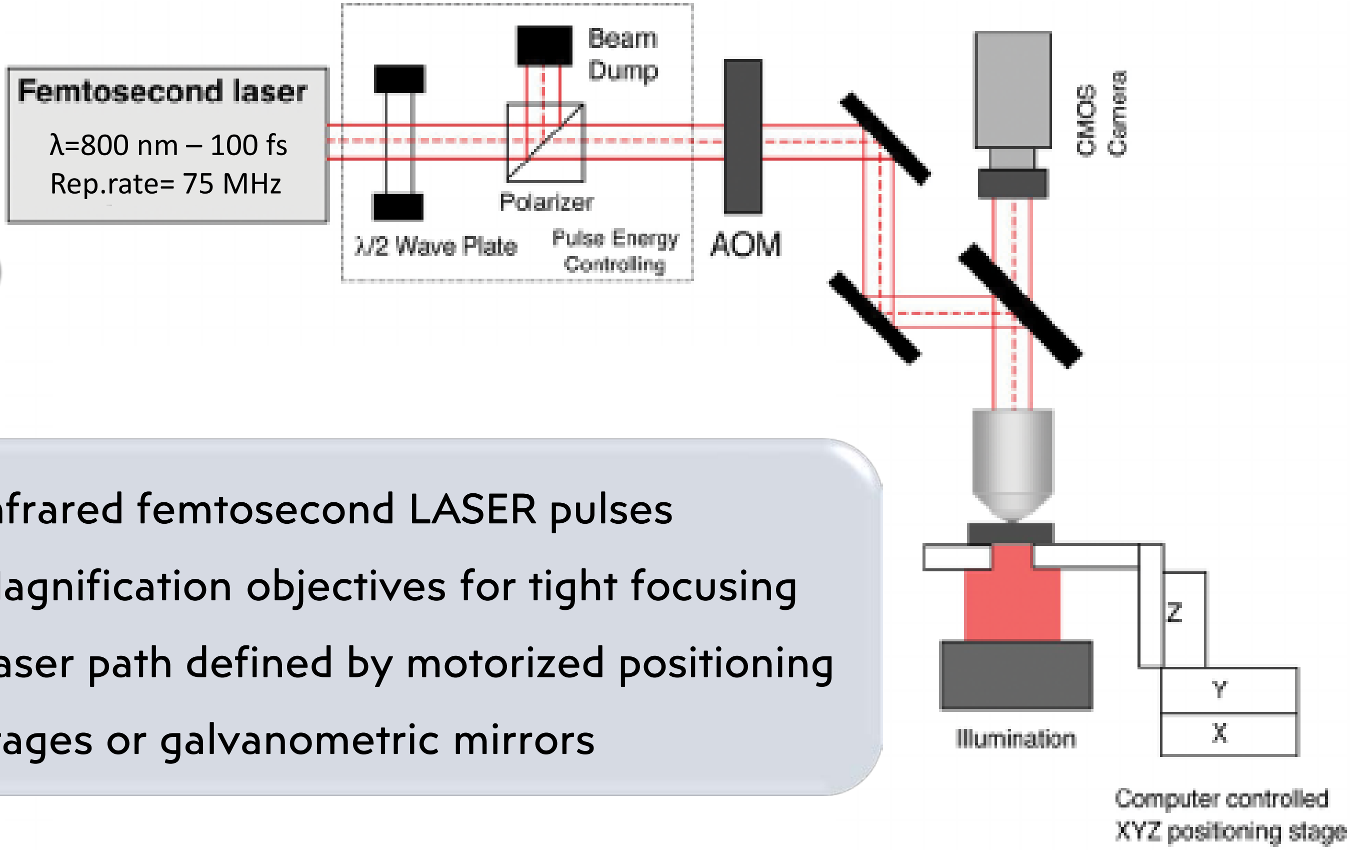
Based on scanning principle	Based on projection principle	Based on non-linear absorption
Tight focusing of the laser beam	Use of a dynamic mask (projector)	Two photon absorption

10^2 m

$10^{-4} \div 10^{-9}$ m

- Micro laser sintering (metals)
- Micro electrochemical deposition (metals)
- Microstereolithography (polymers)
- **2PP - Two photon polymerization (polymers)**





Infrared femtosecond LASER pulses

Magnification objectives for tight focusing

Laser path defined by motorized positioning stages or galvanometric mirrors

10^2 m

$10^{-4} \div 10^{-9}$ m

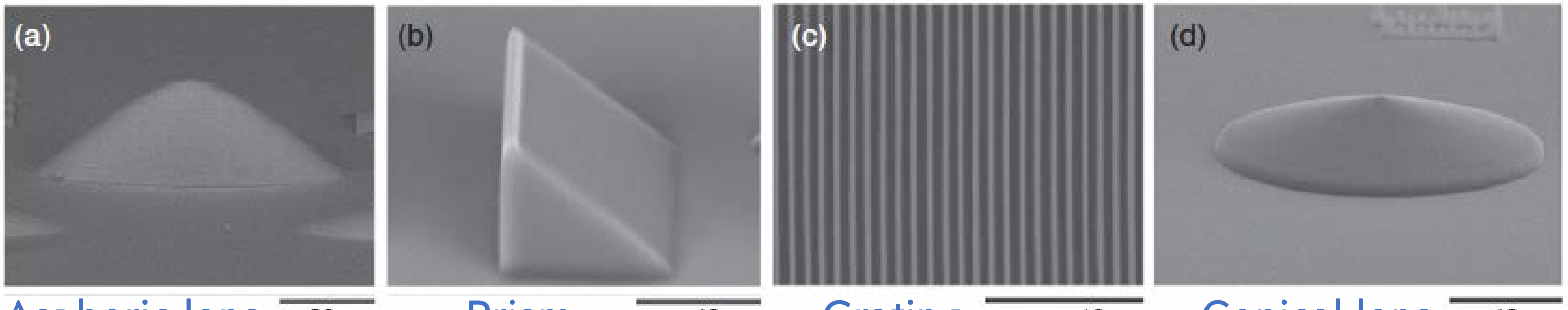
2PP studies are mainly focused in the fields of:

- Optics
- Materials and processes
- MEMS
- Hydrogels and scaffolds
- Microfluidics

3D printing of miniaturized optical elements

Optics

Three dimensional microfabrication, Baldacchini



Aspheric lens | Prism | Grating | Conical lens

In-situ 3D printing of refractive or diffractive elements

Useful for optomechanical devices

Fiber tip structures for integrated photonic devices

Two-photon direct laser writing of beam expansion tapers on single-mode optical fibers – 2019

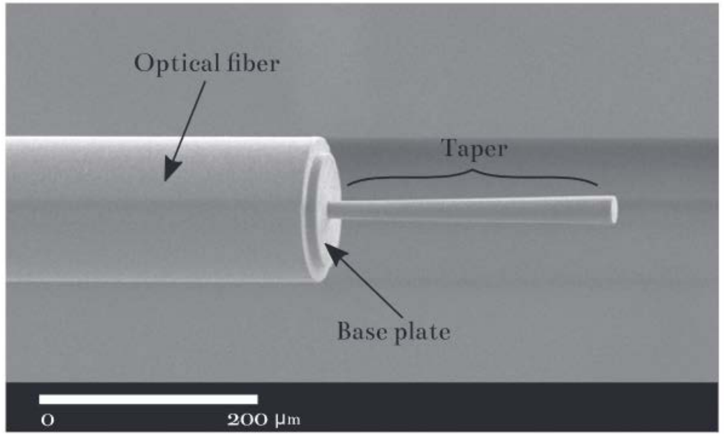
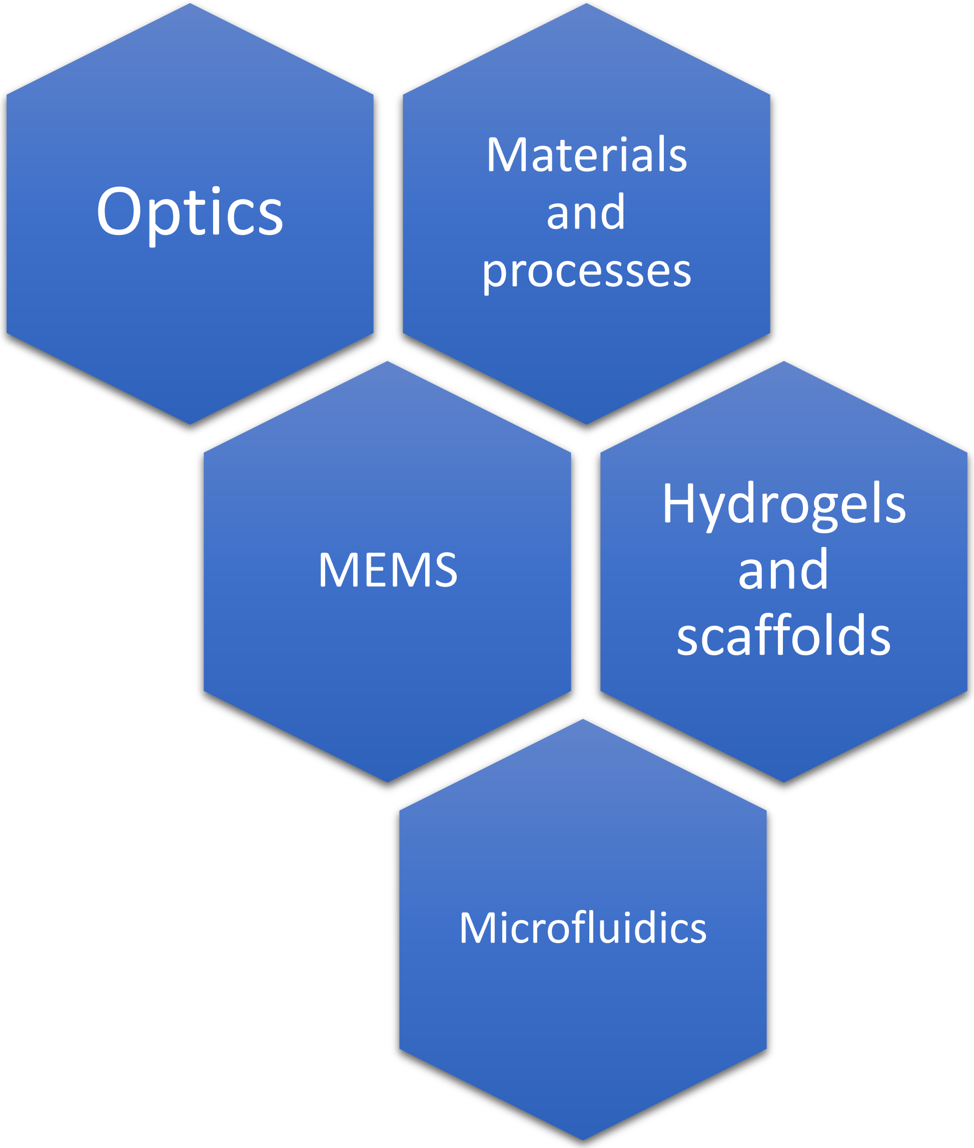


Fig. 8. Scanning electron microscope image of a 3D printed taper structure on top of a cleaved optical fiber tip.

Two photon polymerization (2PP)

2PP studies are mainly focused in the fields of:



2PP of lithographic resists and investigation on new materials and fabrication processes

Materials and processes

Additive Manufacturing of Nanostructures That Are Delicate, Complex, and Smaller than Ever - 2019

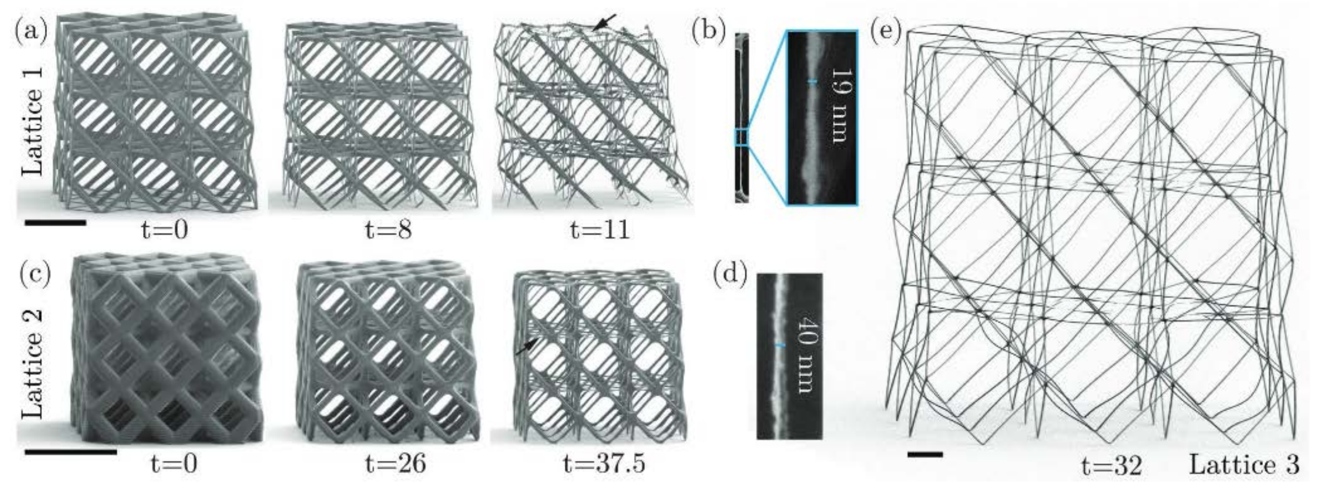


Figure 1. a) Progressive etching of Lattice 1, comprising elliptical struts. The arrow indicates the strut shown in (b) with high magnification. c) Progressive etching of Lattice 2, comprising equiaxed struts. The arrow indicates the strut shown in (d) with high magnification. e) Lattice 3 at the final stage of etching. All scale bars are 10 μm and all etching times *t* are reported in minutes.

2PP + Oxygen plasma etching

New fabrication concept to reach high precision shape control

and

to print delicate structures

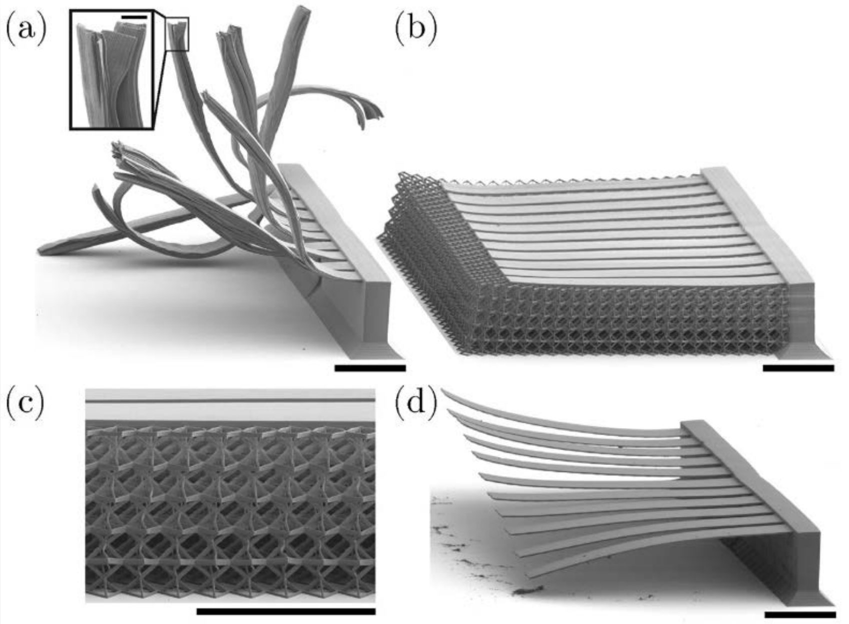
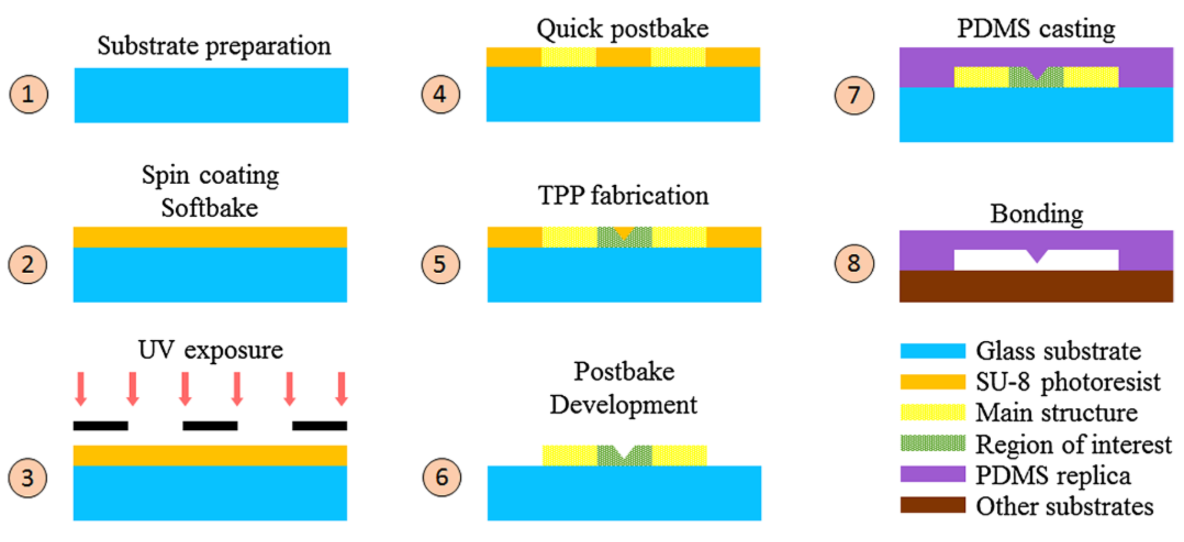


Figure 3. a) Fabrication errors and distortions that occur during exposure and development of a beam array with no supports. Inset shows stacking errors between subsequent layers. b) Defect free beam array supported by an octahedral microlattice. c) Magnified view of one beam resting on the bed of support material. d) Beam array after support material is removed. The curvature of each beam is achieved with a gradient in exposure through the thickness of each beam. Scale bar in the inset image is 5 μm, all others are 50 μm.

2PP of lithographic resists and investigation on new materials and fabrication processes

Materials and processes

Soft lithography based on photolithography and two-photon polymerization - 2018



Double SU-8 patterning:

photolithography and 2PP

Passive mixer obtained after PDMS casting

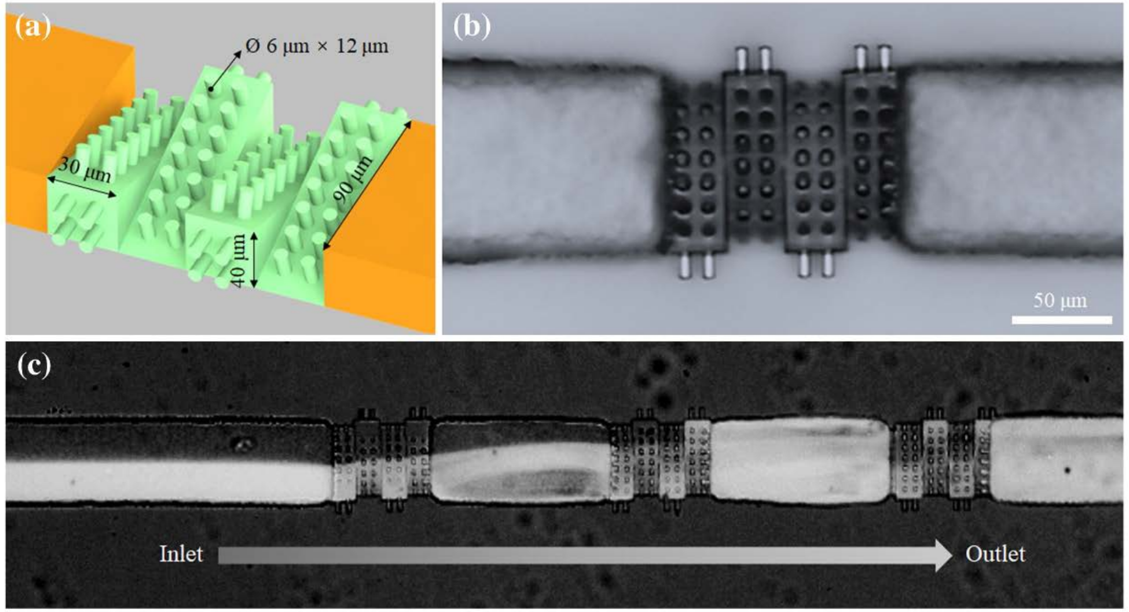
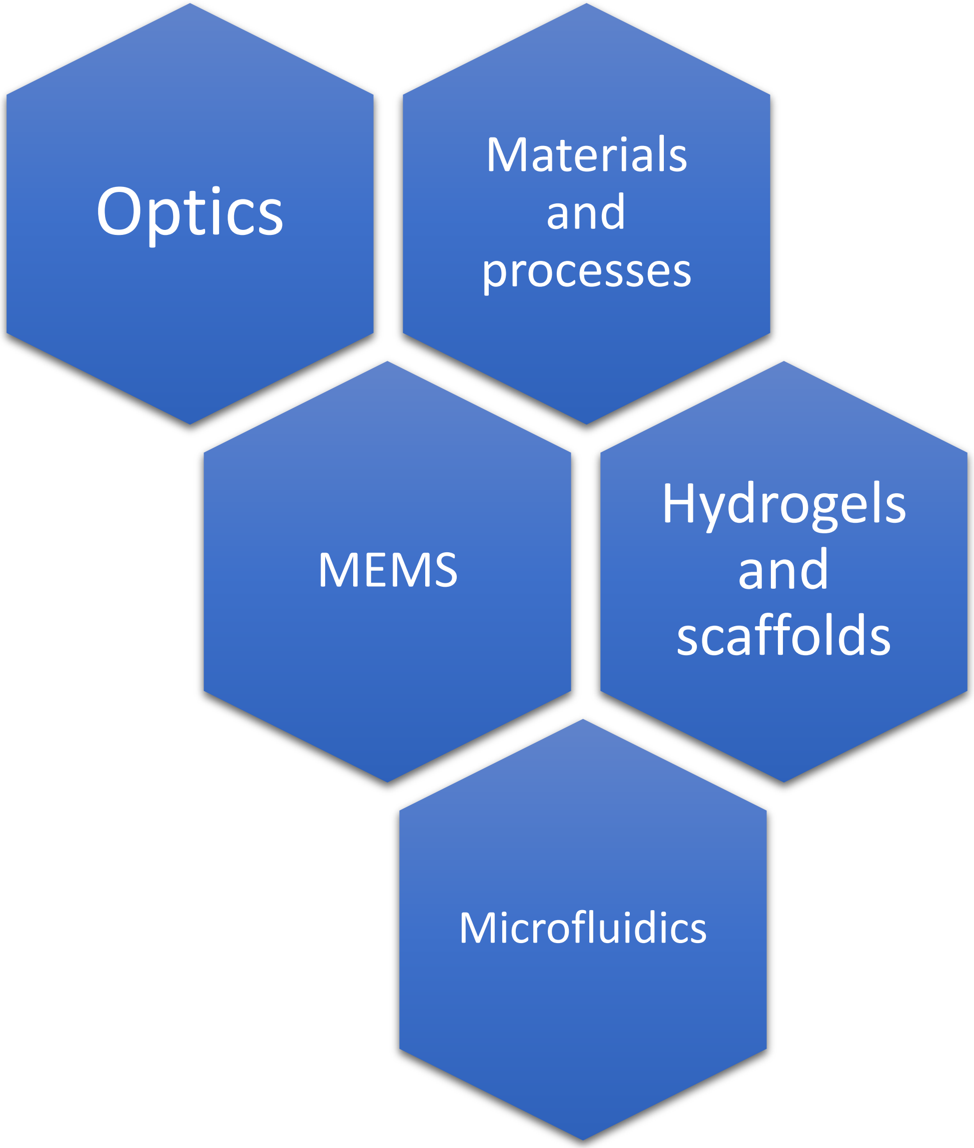


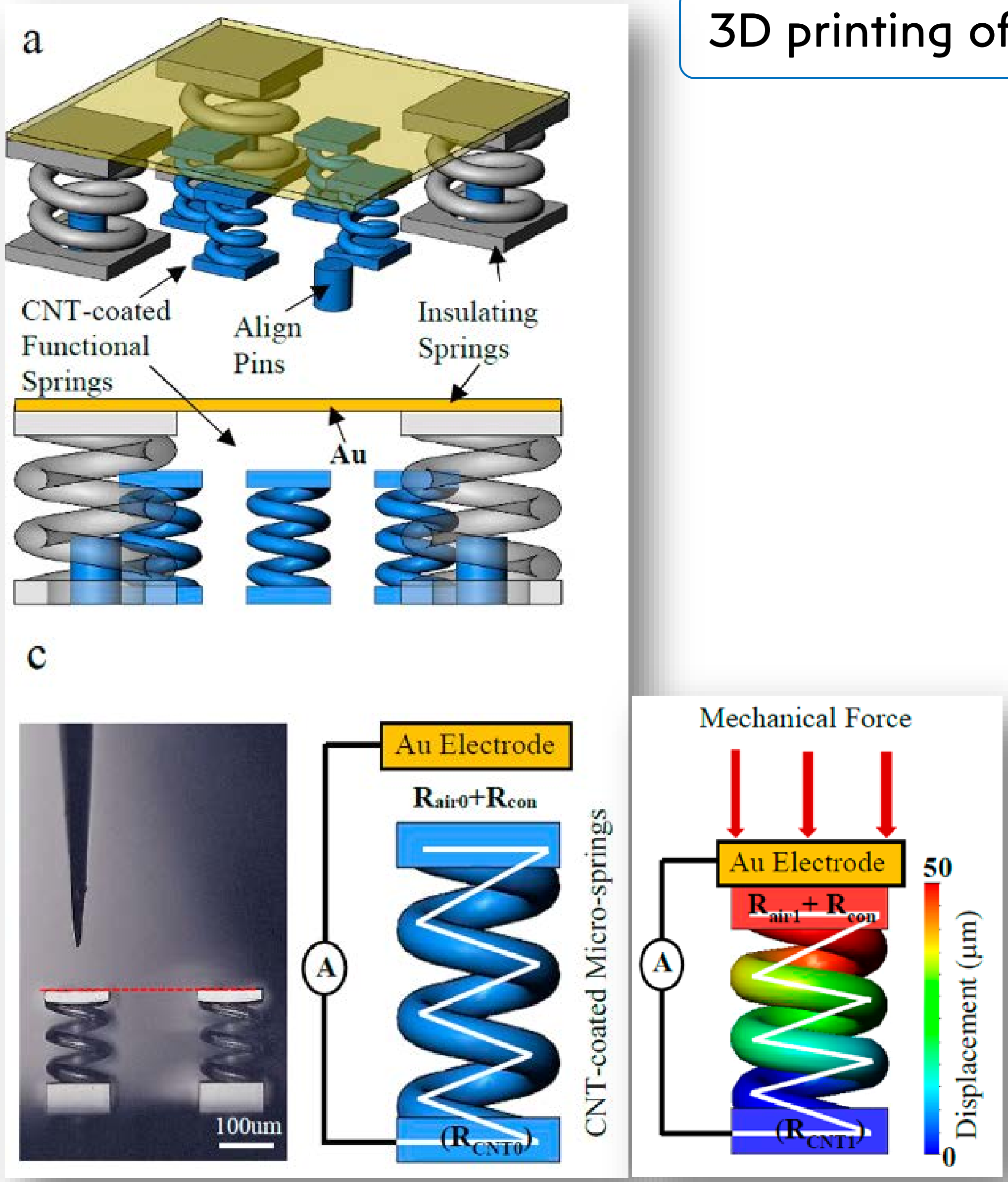
Fig. 8 A passive mixer fabricated using hybrid fabrication method. **a** Schematic illustration of the mixing component composed of four triangular blocks. **b** Image of the mixing component in a fabricated soft lithography master mould. **c** Image that showed a complete mixing achieved after two mixing components

2PP studies are mainly focused in the fields of:

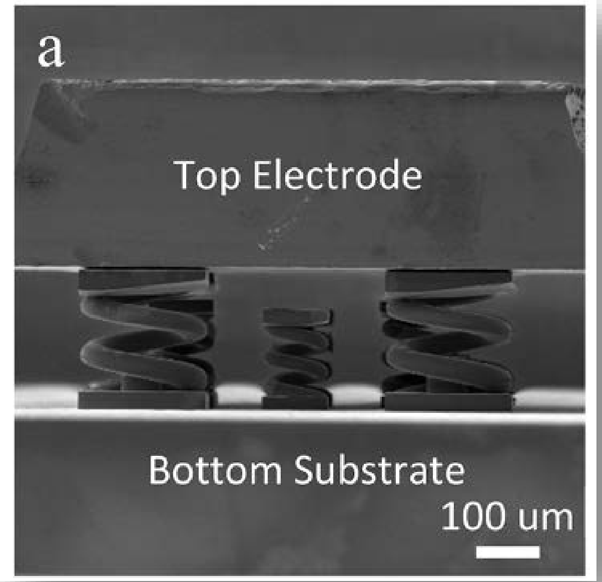


3D printing of Micro Electro-Mechanical Systems

MEMS



Micro-springs coated with CNTs for real time force sensing



Carbon-Nanotube-Coated 3D Microspring Force Sensor for MedicalApplications – 2019

3D printing of Micro Electro-Mechanical Systems

MEMS

Multimaterial 3D Printing for Microrobotic Mechanism – 2018

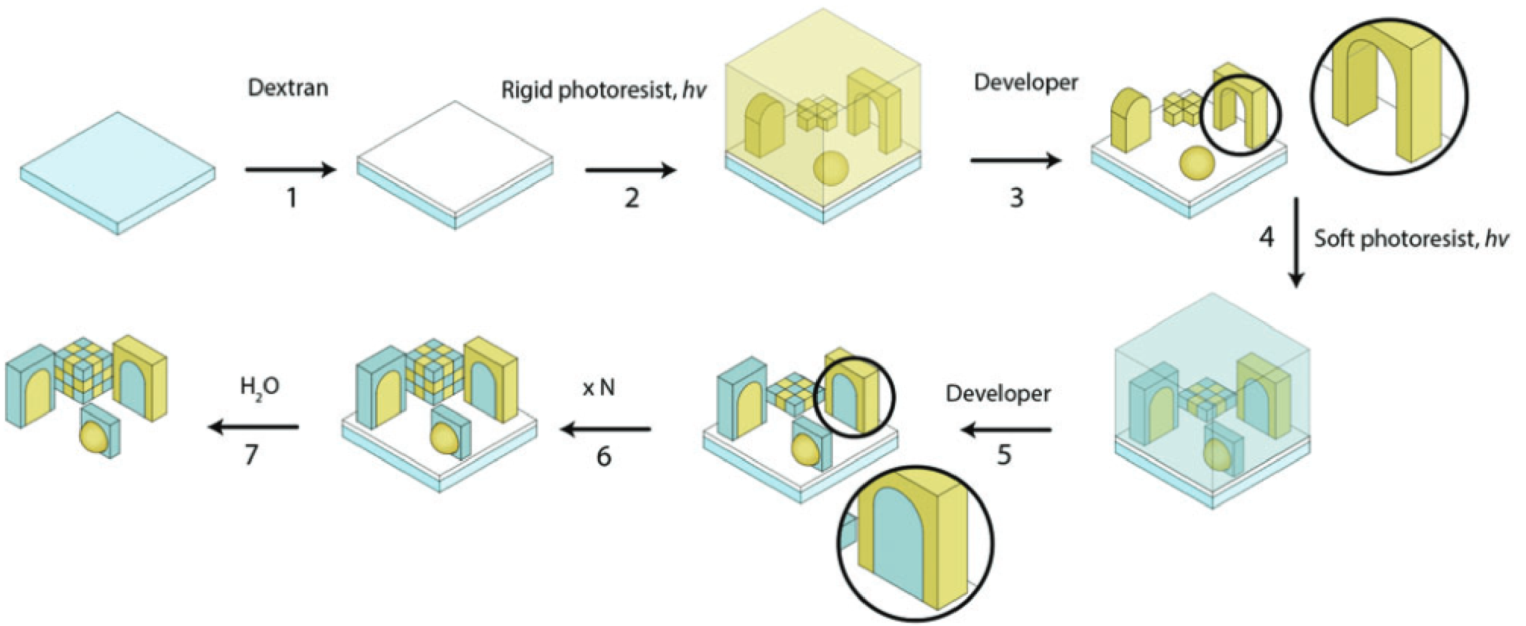


FIG. 1. Multimaterial fabrication scheme. 1. Spin-coating of dextran sacrificial layer onto ITO/glass substrate, 2. TPP printing of Photoresist No. 1 (e.g., IP-S), 3. Development of Photoresist No. 1 printed structures using PGMEA, 4. TPP printing of Photoresist No. 2 (e.g., UDA), 5. Development of Photoresist No. 2 printed structures using PGMEA. Note the material printed underneath an existing structure, 6. Complementing the structures via additional iterations of steps 2–5, 7. Release of the multimaterial printed structures from the surface using water. PGMEA, propylene glycol monomethyl ether acetate; TPP, two-photon polymerization; UDA, urethane diacrylate. Color images are available online.

Alternate soft and rigid materials to obtain small-scale robots

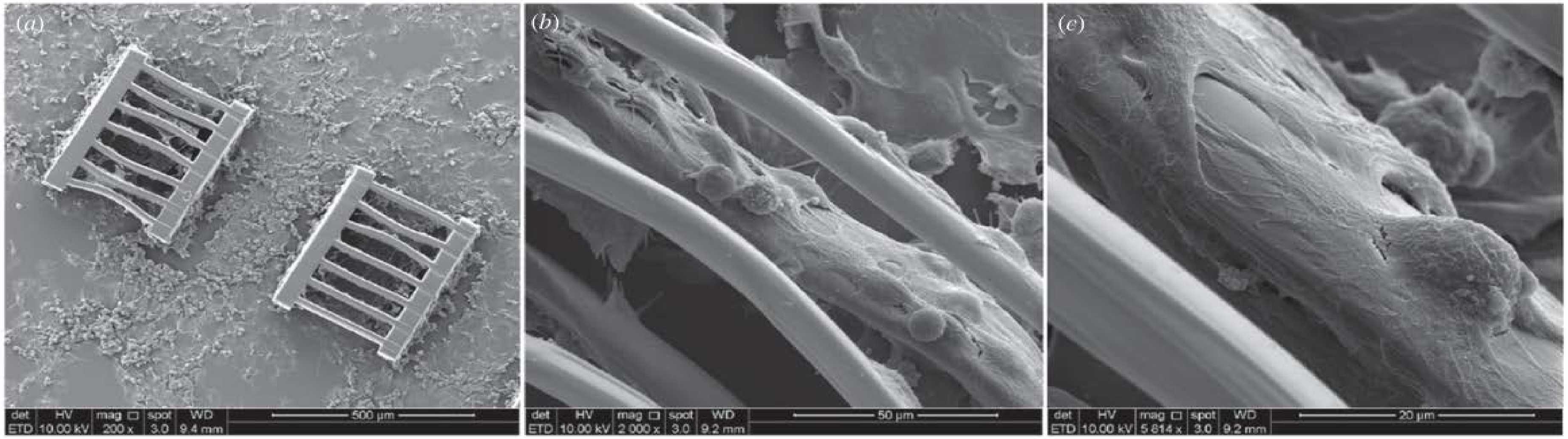
2PP studies are mainly focused in the fields of:

- Optics
- Materials and processes
- MEMS
- Hydrogels and scaffolds
- Microfluidics

3D printing of structures for cells cultures

Hydrogels and scaffolds

Melissinaki V, Gill AA, Ortega I, Vamvakaki M, Ranella A, Haycock JW, et al. Direct laser writing of 3D scaffolds for neural tissue engineering applications. Biofabrication. 2011;3(4).



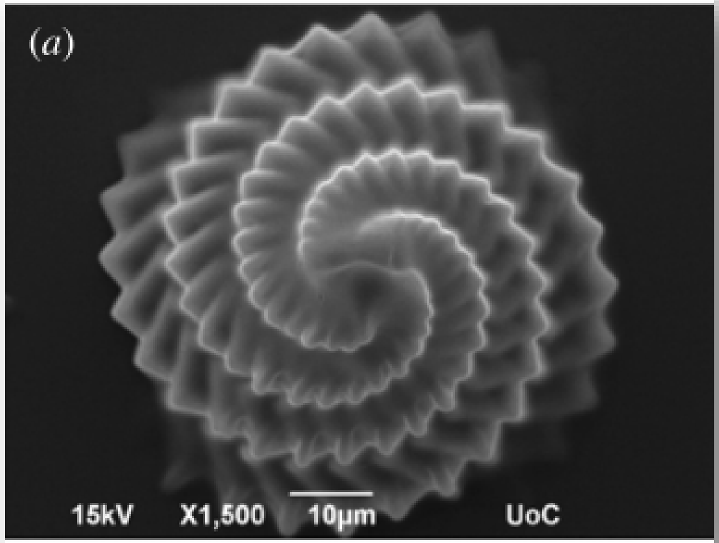
Study the influence of substrate topology on cells growth

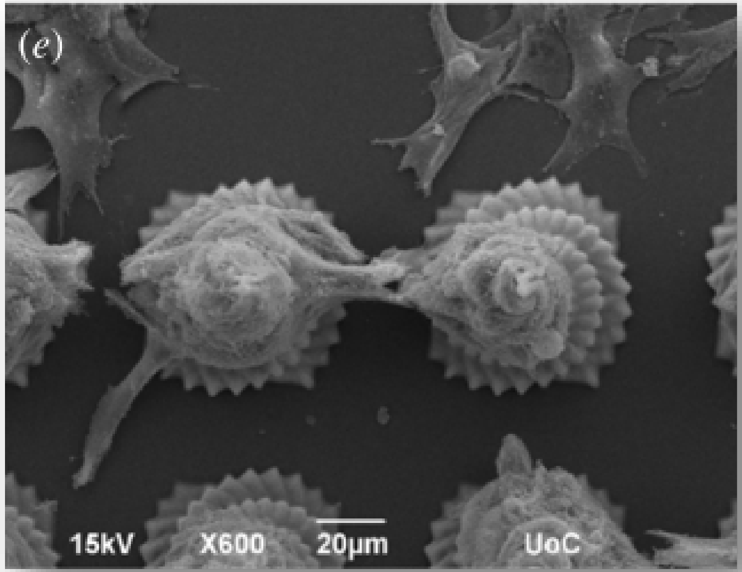
Guidewires width = 10-20 μm

Neuronal cells

3D printing of structures for cells cultures

Hydrogels and scaffolds





Melissinaki V, Gill AA, Ortega I, Vamvakaki M, Ranella A, Haycock JW, et al. Direct laser writing of 3D scaffolds for neural tissue engineering applications. Biofabrication. 2011;3(4).

Study the influence of substrate topology on cells growth

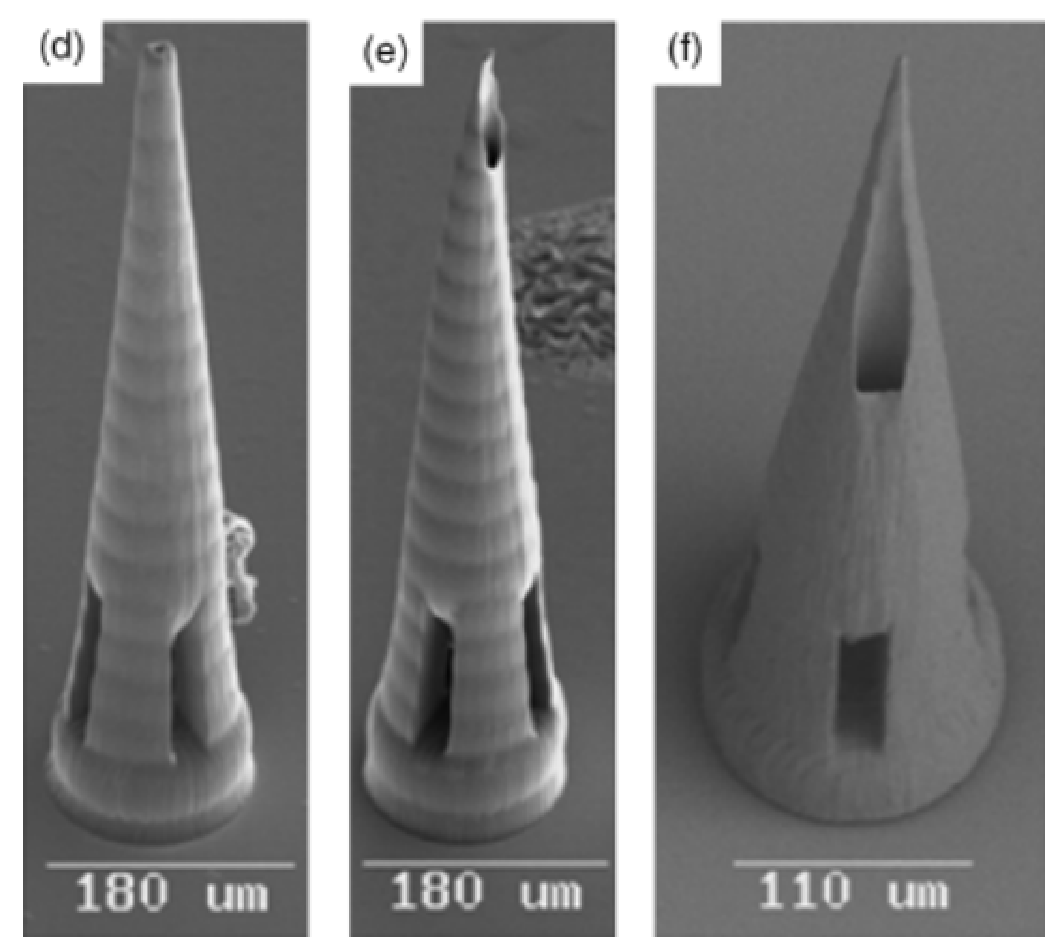
Seashell structures

2PP studies are mainly focused in the fields of:

- Optics
- Materials and processes
- MEMS
- Hydrogels and scaffolds
- Microfluidics

3D printing of micrometric devices for liquid flow control

Microfluidics



Ovsianikov A, Chichkov B, Mente P, Monteiro-Riviere NA, Doraiswamy A, Narayan RJ. Two Photon Polymerization of Polymer Ceramic Hybrid Materials for Transdermal Drug Delivery. Int J Appl Ceram Technol. 2007 Jan;4(1):22–9.

Transdermal micro needles

Pros:

- Embeddable in portable medical devices
- Pain and damage at the injection site reduced
- May allow diffusion over a period of time

800 μm long needle

3D printing of micrometric devices for liquid flow control

Microfluidics

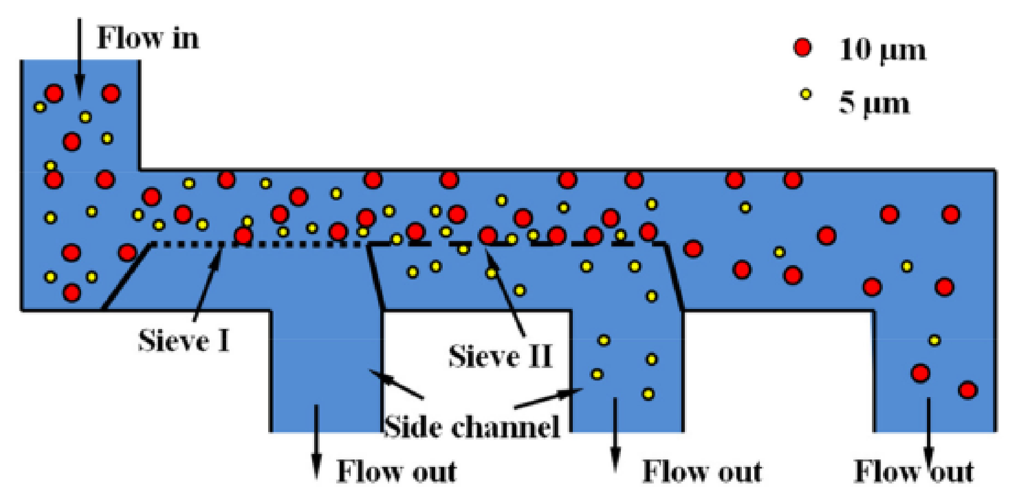
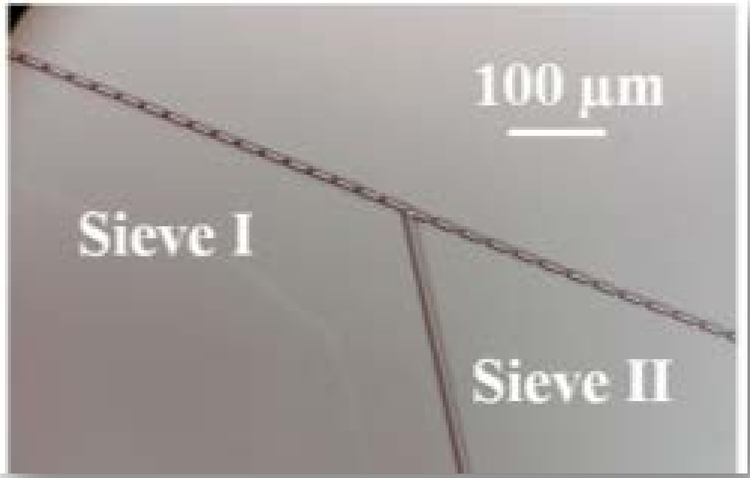


Fig. 2. Schematic illustration of the particle sorter designed in this study.

Femtosecond Laser Microfabricated Microfilters for Particle–Liquid Separation in a Microfluidic Chip – 2019

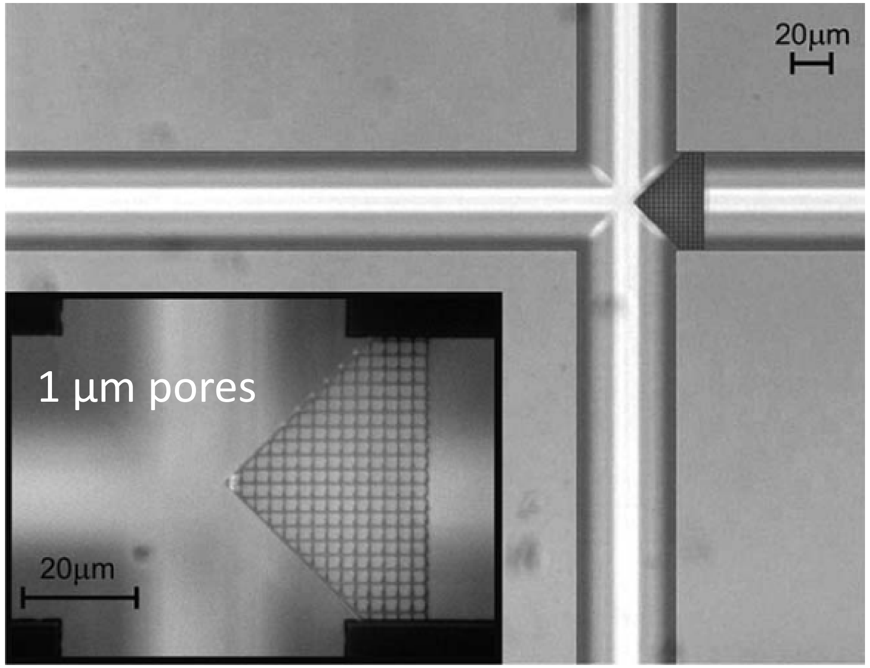


Micrometric filters

In-situ polymerization of filtering structures for particles separation from liquid samples

3D printing of micrometric devices for liquid flow control

Microfluidics



Amato L, Gu Y, Bellini N, Eaton SM, Cerullo G, Osellame R. Integrated three-dimensional filter separates nanoscale from microscale elements in a microfluidic chip. Lab Chip. 2012;12(6):1135.

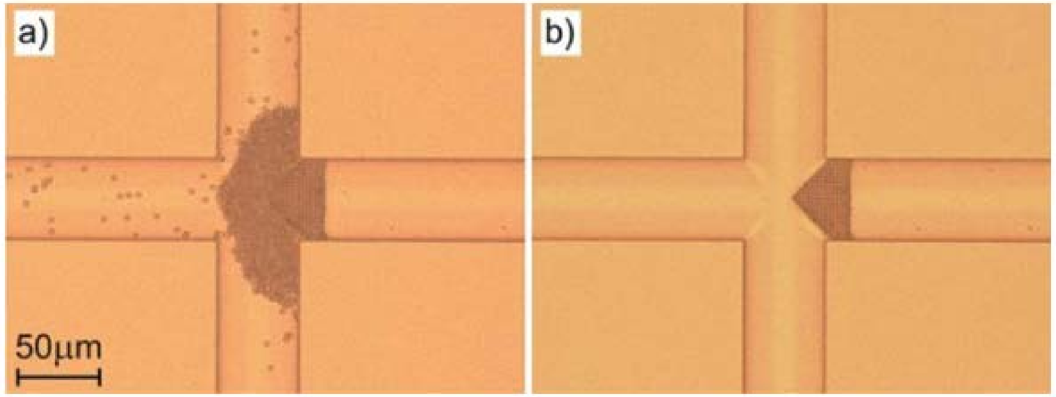


Fig. 7 (a) Image of the filter after 25 minutes in the slow filtering regime. (b) The filter after cleaning by injection of buffer solution from well 4 with a syringe.

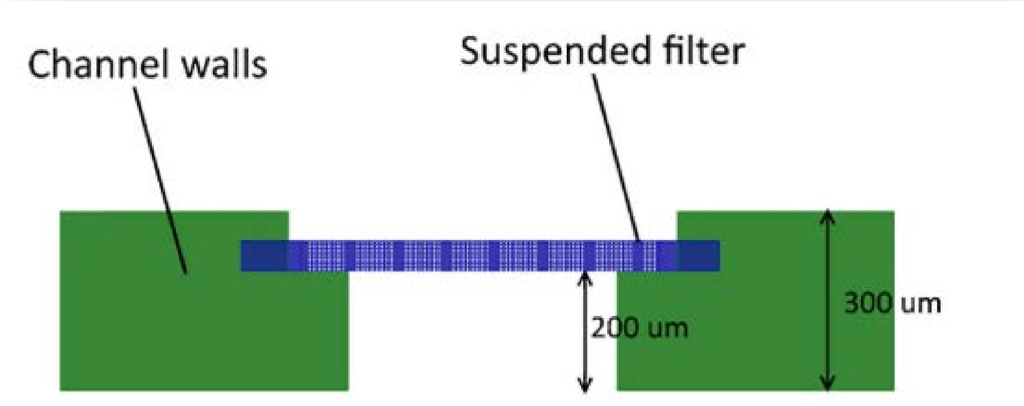
Micrometric filters

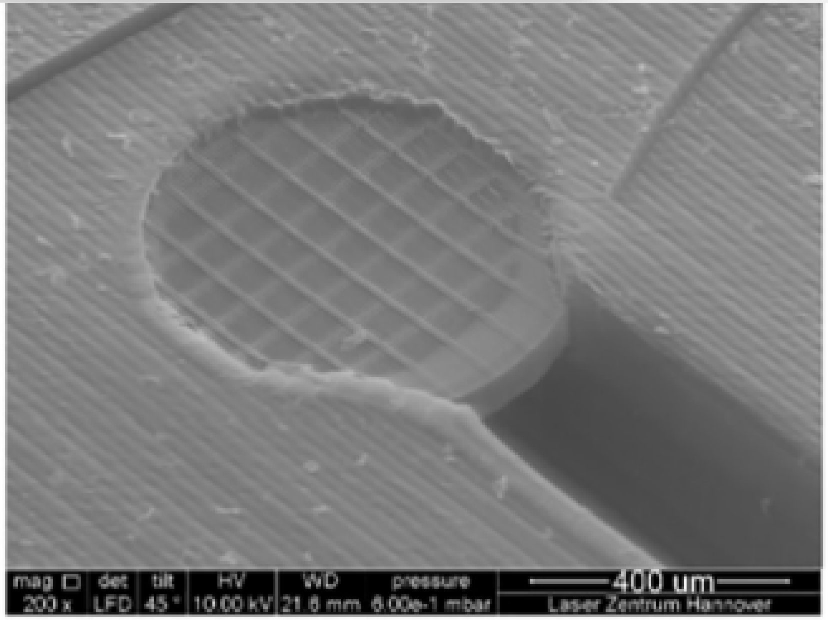
In-situ polymerization of filtering structures for particles separation from liquid samples

3D printing of micrometric devices for liquid flow control

Microfluidics

Perrucci F, Bertana V, Marasso SL, Scordo G, Ferrero S, Pirri CF, et al. Optimization of a suspended two photon polymerized microfluidic filtration system. Microelectron Eng. 2018;195(February):95–100.



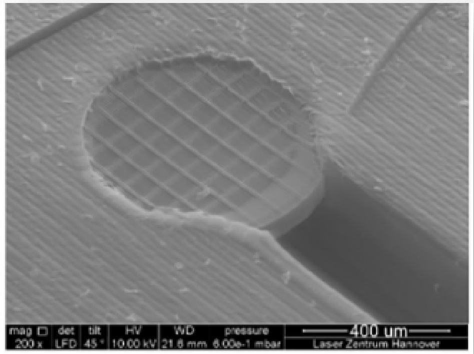


Micrometric filters

Innovative printing strategy for 4 μm pores

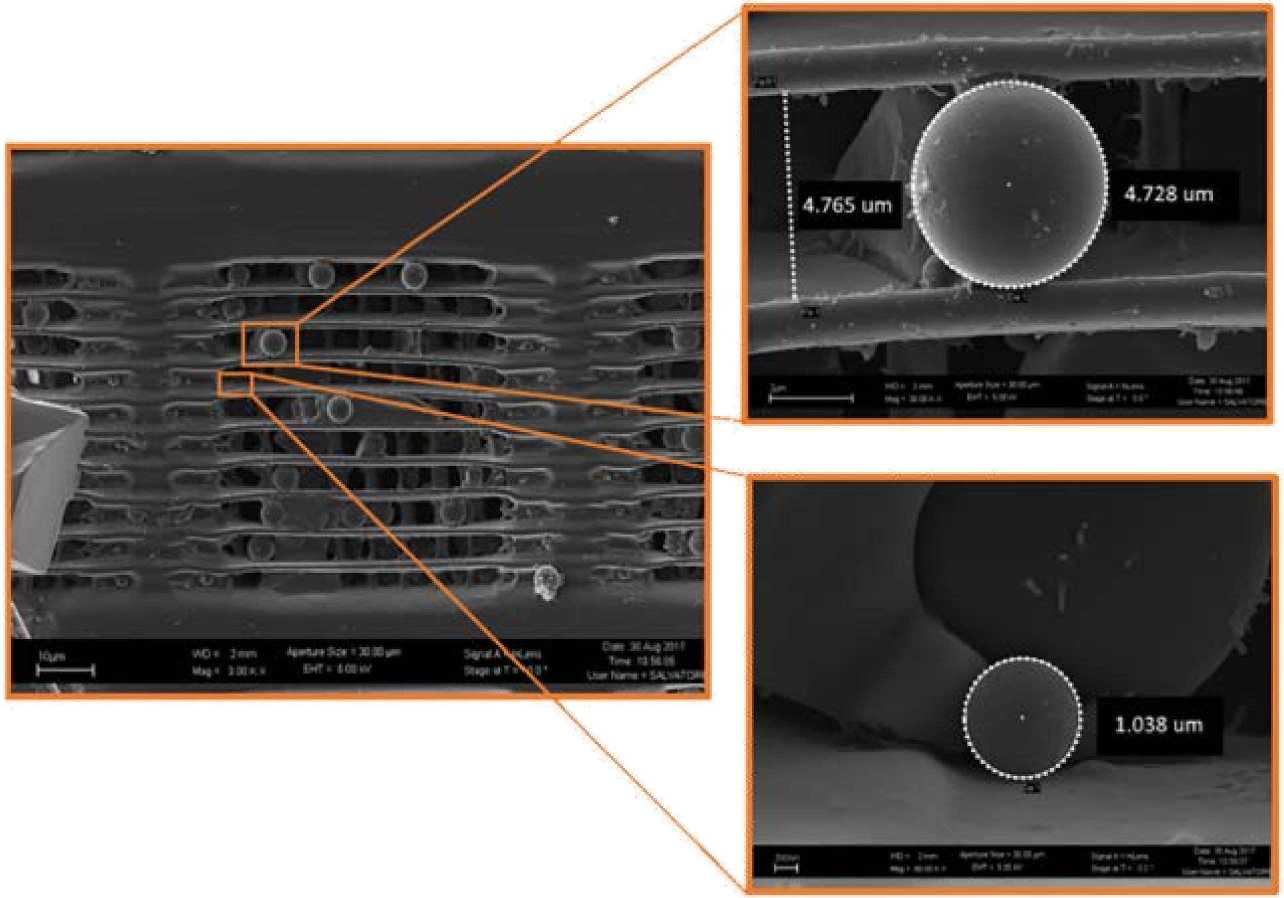
filter printing in limited time

LASER ZENTRUM HANNOVER e.V.



3D printing of micrometric devices for liquid flow control

Microfluidics

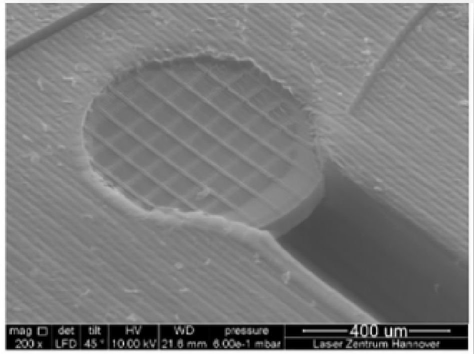


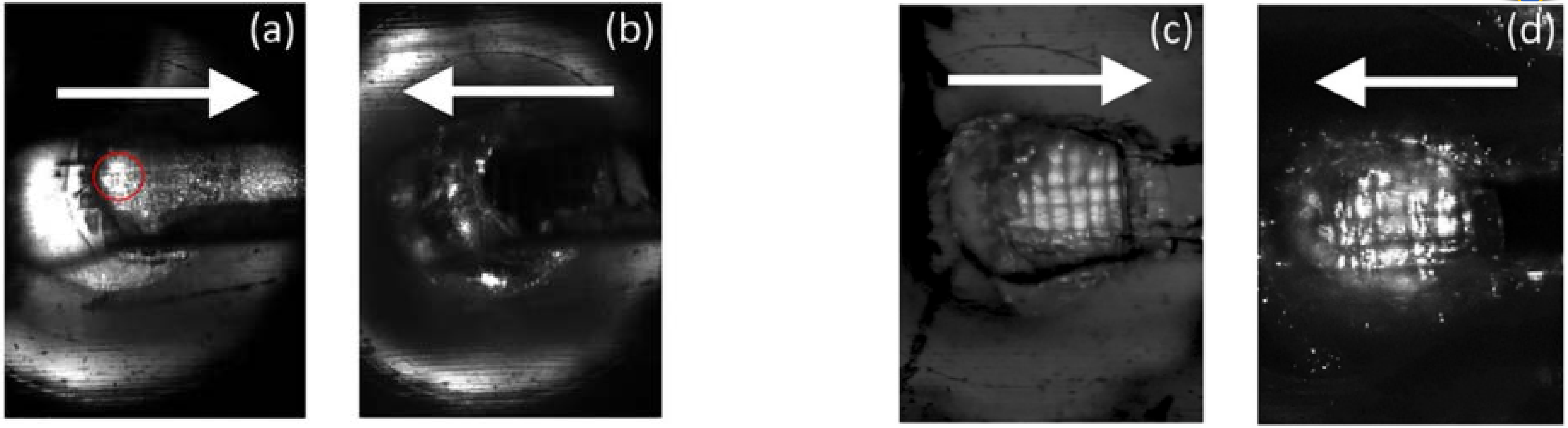
4 μm particles get blocked while 1 μm particles pass

LASER ZENTRUM HANNOVER e.V.

3D printing of micrometric devices for liquid flow control

Microfluidics



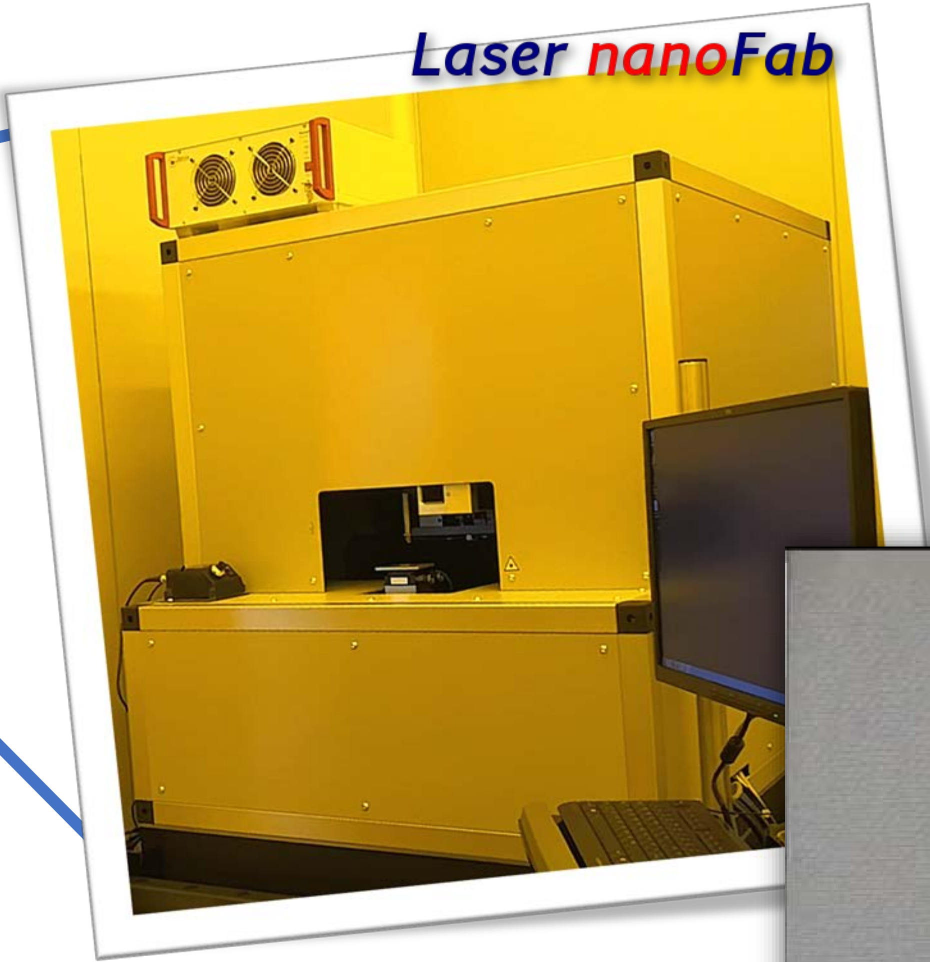


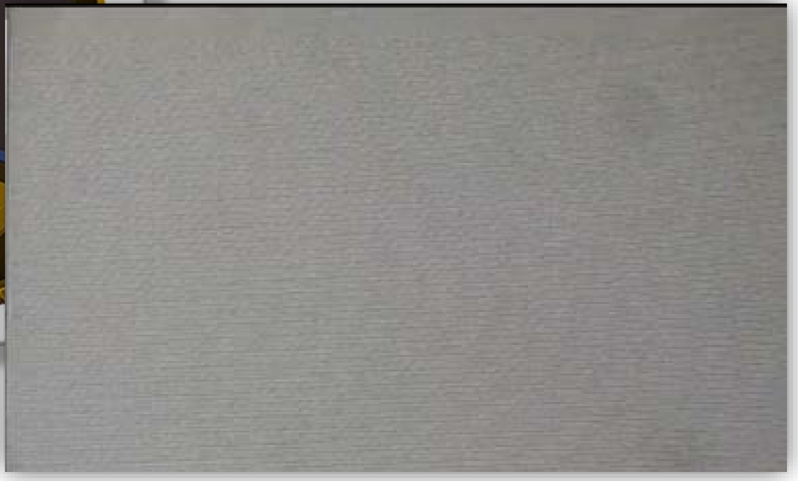
1 µm particles

4 µm particles

LASER ZENTRUM HANNOVER e.V.

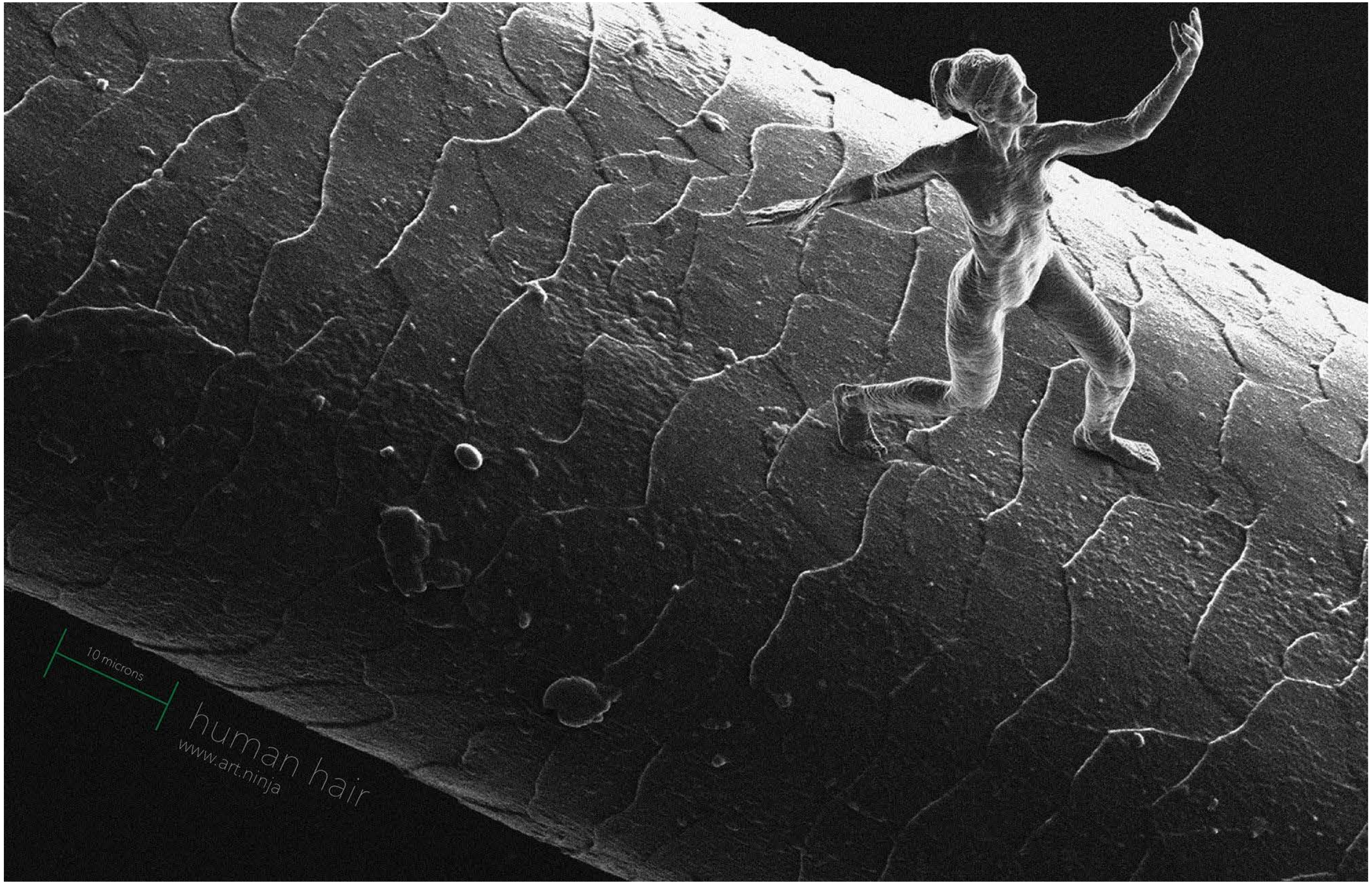
Cleanroom for microsystems fabrication





- www.3dnatives.com
- Bertsch, A., Zissi, S., Jézéquel, J. et al. Microstereophotolithography using a liquid crystal display as dynamic mask-generator. Microsystem Technologies 3, 42–47 (1997).
- A. Bertsch, et al., Nouveau procédé de microstéréolithographie utilisant des filtrages dynamiques. in 4èmes assises européennes du prototypage rapide, Remark S.A., Paris, France, 1995
- www.3dmicroprint.com
- www.exaddon.com

Thank you for your attention!



https://www.jontyhurwitz.com/portfolio/nano/

Valentina Bertana, PhD
Politecnico di Torino
valentina.bertana@polito.it