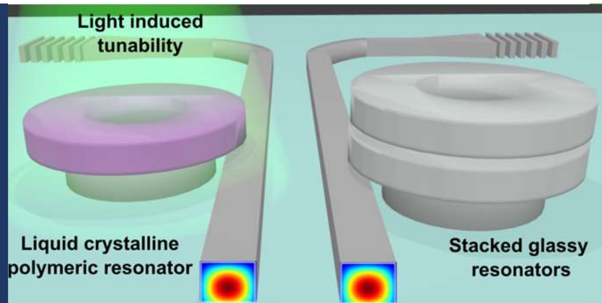
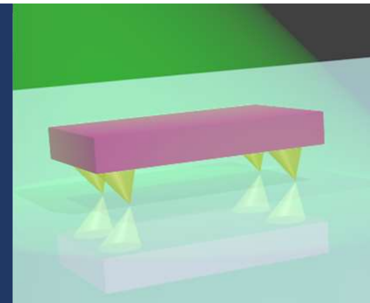
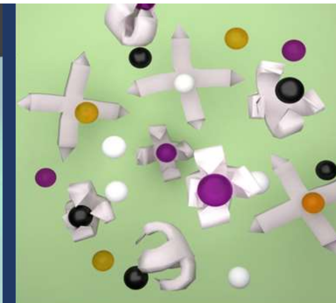
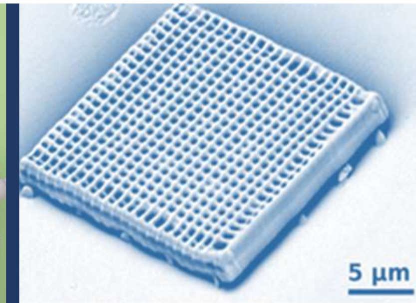



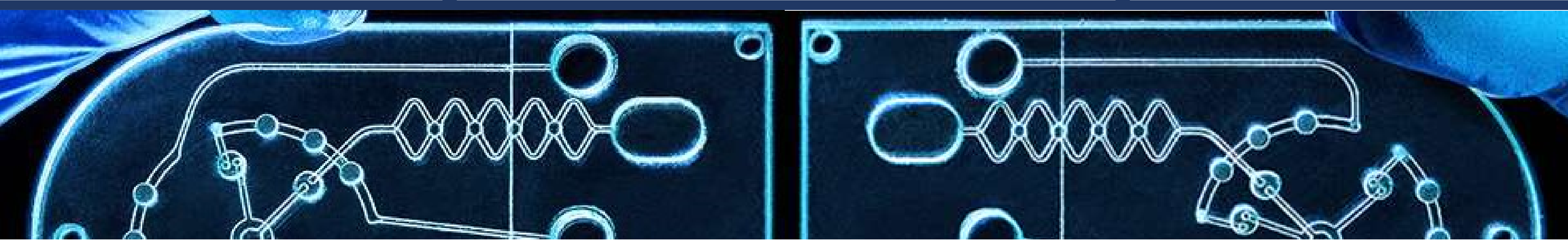




Shape-changing microstructures for multifunctional microfluidics

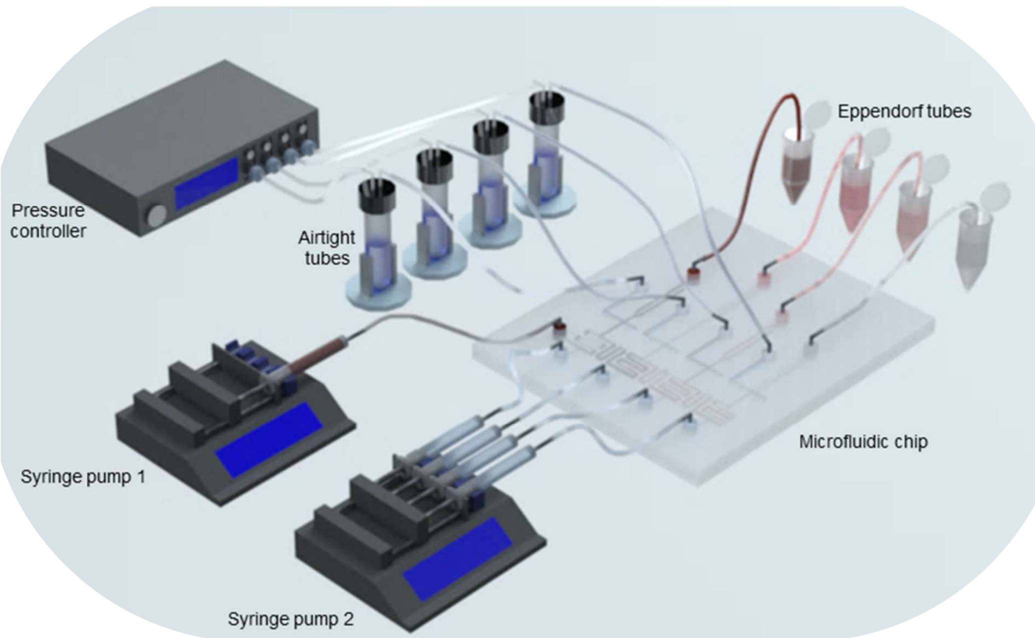
S. Nocentini, S. Donato, D. Martella, C. Credi, C. Parmeggiani and D. S. Wiersma
nocentini@lens.uniti.it, s.nocentini@inrim.it

Lens European Laboratory for Non-Linear Spectroscopy
INRiM Istituto Nazionale di Ricerca Metrologica
BioQantSense
European Commission
CNR-INO Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche

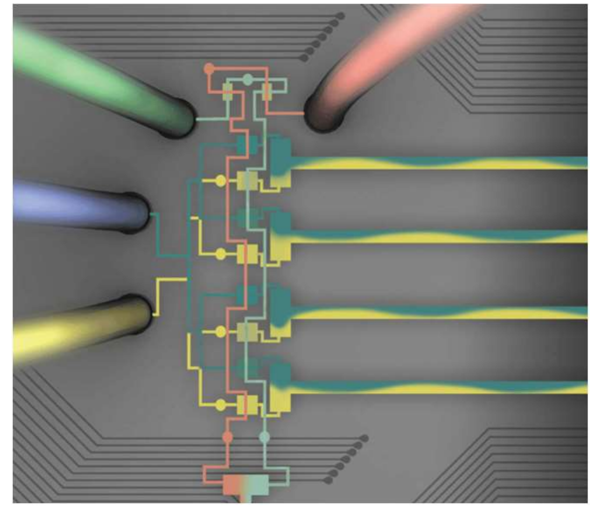
Belgrade, Photonica23, 28 August 2023



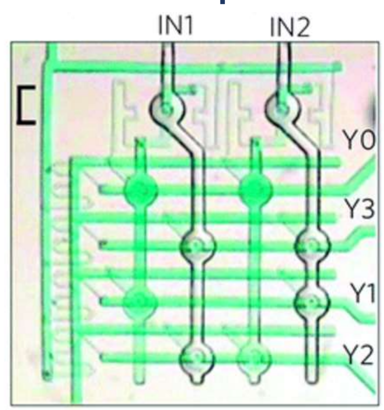
Microfluidics integration for multi-functional platforms



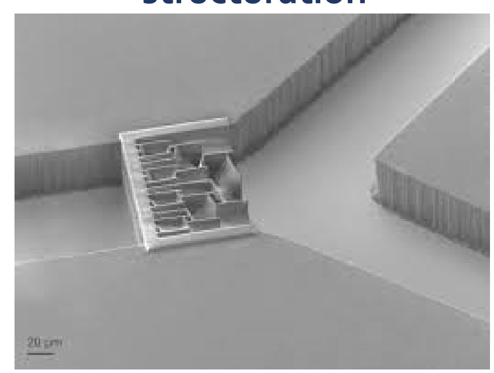
NEXT GENERATION MICRO-FLUIDICS



Active components



3D integration and structuration



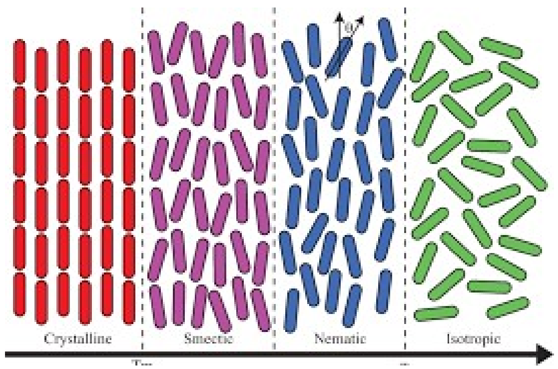
BioQantSense

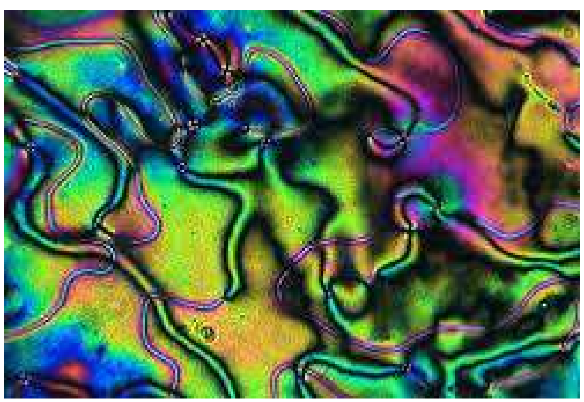
Shape-changing microstructures for multifunctional microfluidics

- Responsive materials : Light-driven **Liquid crystalline networks**
- **Direct laser writing** for 3D integration on different substrates
- **Microrobots** moving in dry and liquid environments
- **Photonic structures** : the role of water in the tuning mechanism
- Encoding information in 3D printed microstructures for **smart labels**
- BioQantSense : Preliminary results of 3D micro printing in PDMS channels

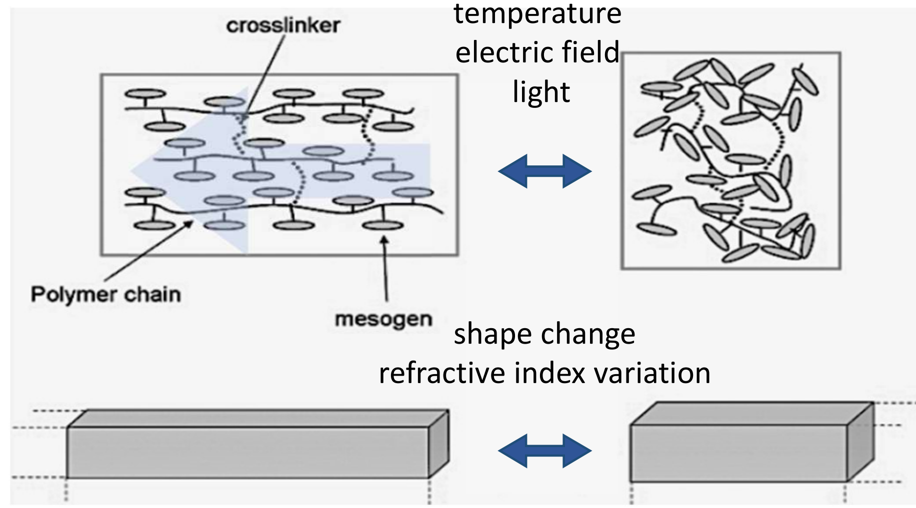
liquid crystals and liquid crystalline networks

Liquid crystals

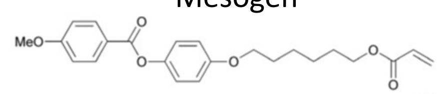




Liquid crystalline networks



Mesogen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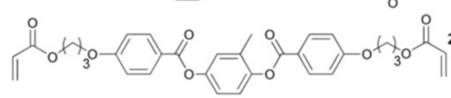
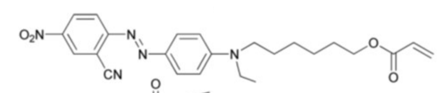

2

Cross-linker

Azo-dye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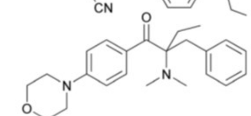
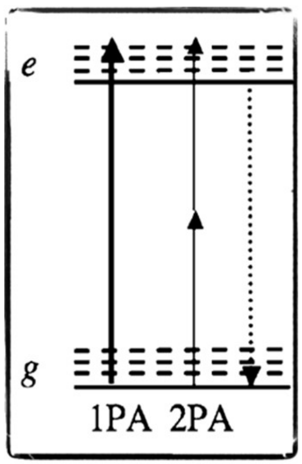


Photo-initiator

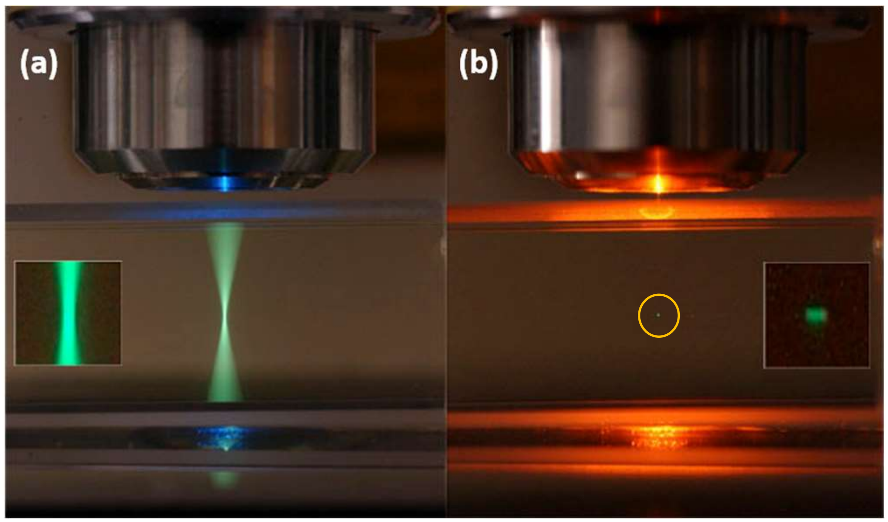
two-photon direct laser writing (TP-DLW)

Two-photon absorption polymerization for 3D (or 4D) nano patterning



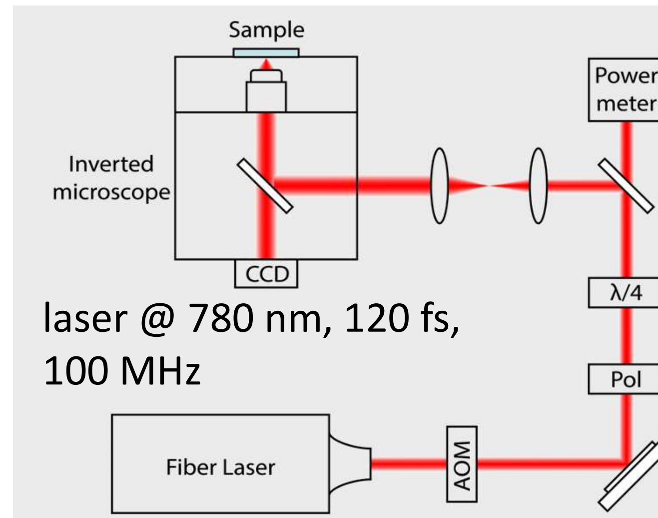
Single photon excitation

Two photon excitation



$$n^{(1)} = \sigma(\nu) N_g \frac{I}{h\nu}$$

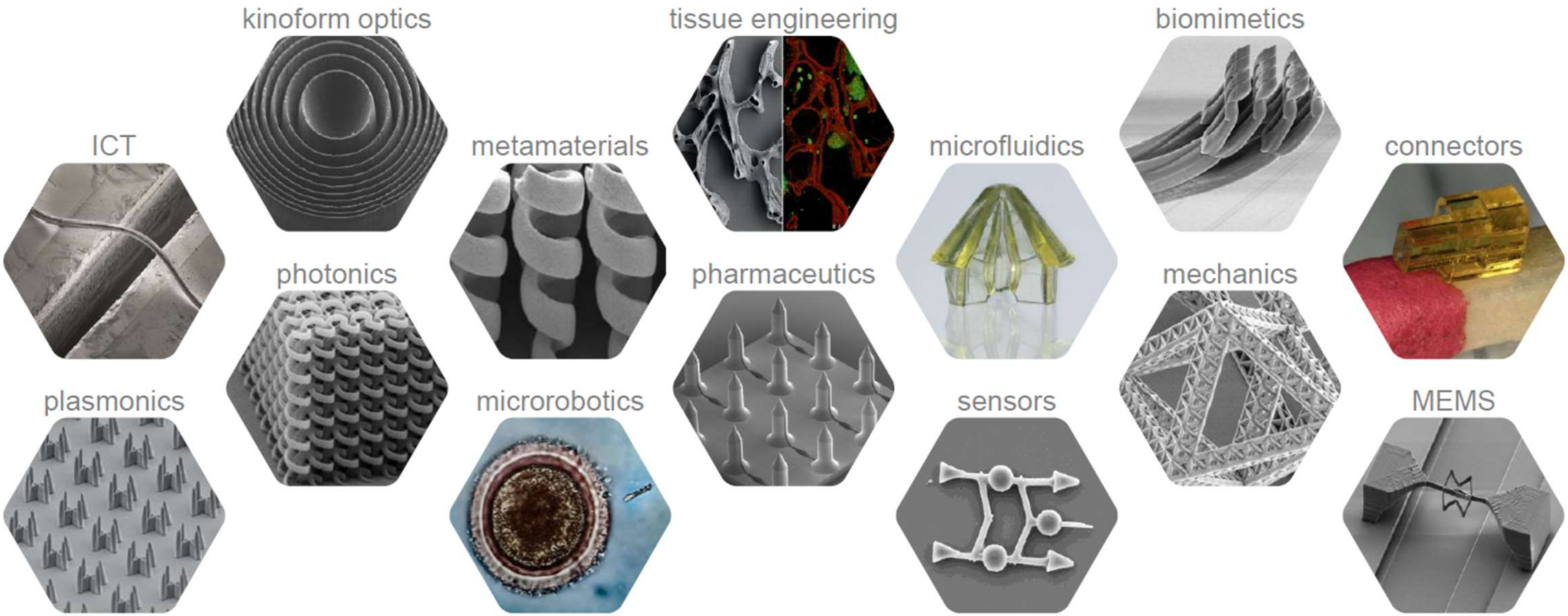
$$n^{(2)} = \frac{1}{2}\delta(\nu) N_g \left(\frac{I}{h\nu}\right)^2$$



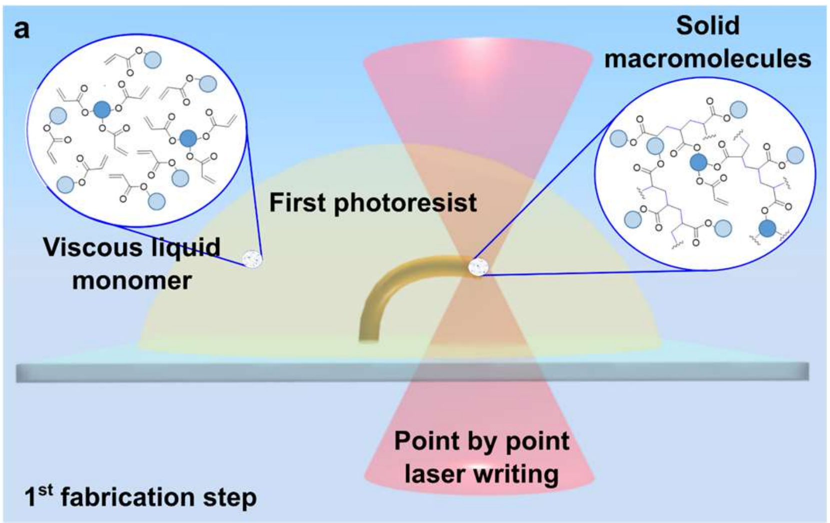
laser @ 780 nm, 120 fs, 100 MHz

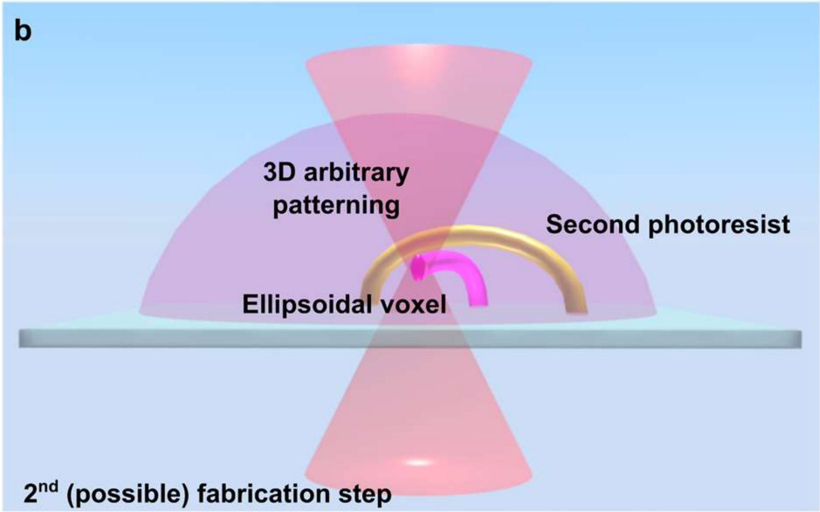
two-photon direct laser writing (TP-DLW)

Glassy resists

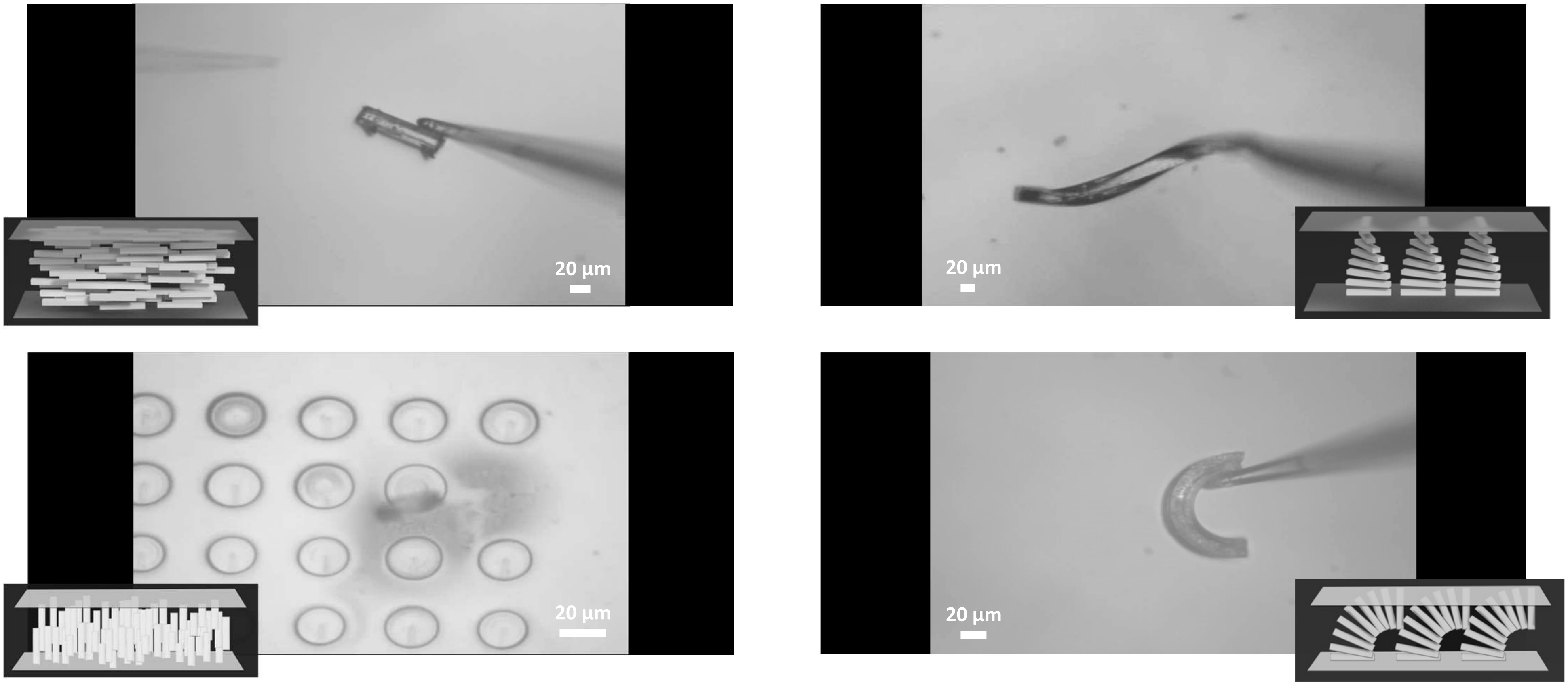


two-photon direct laser writing (TP-DLW)

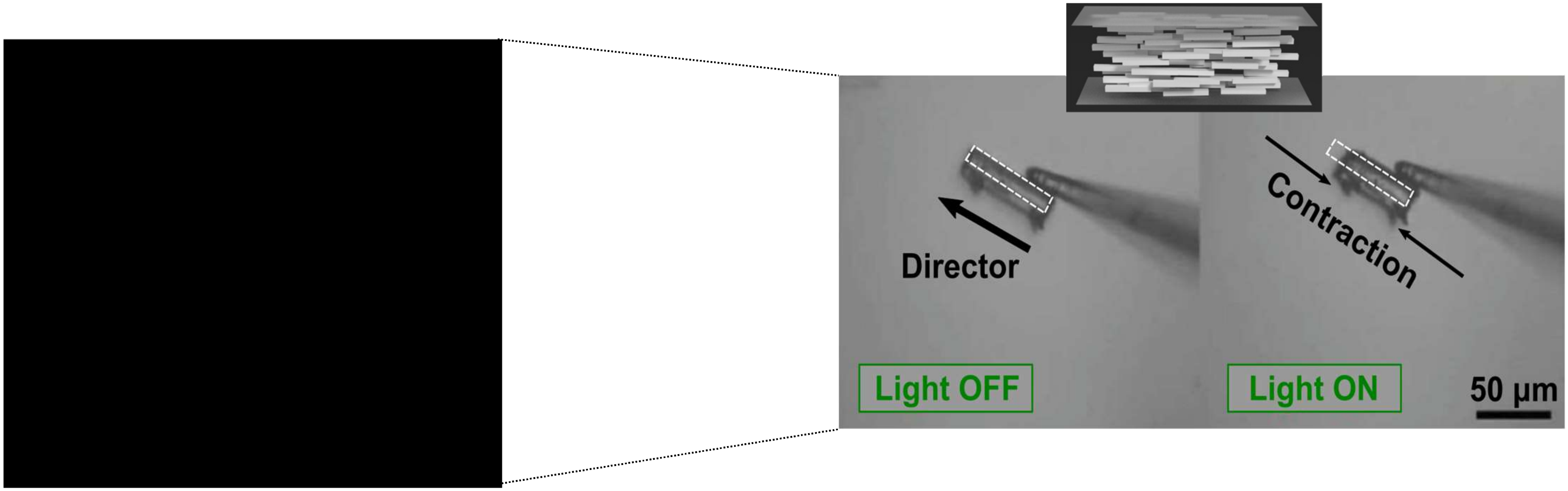




liquid crystalline network: alignment control and motion

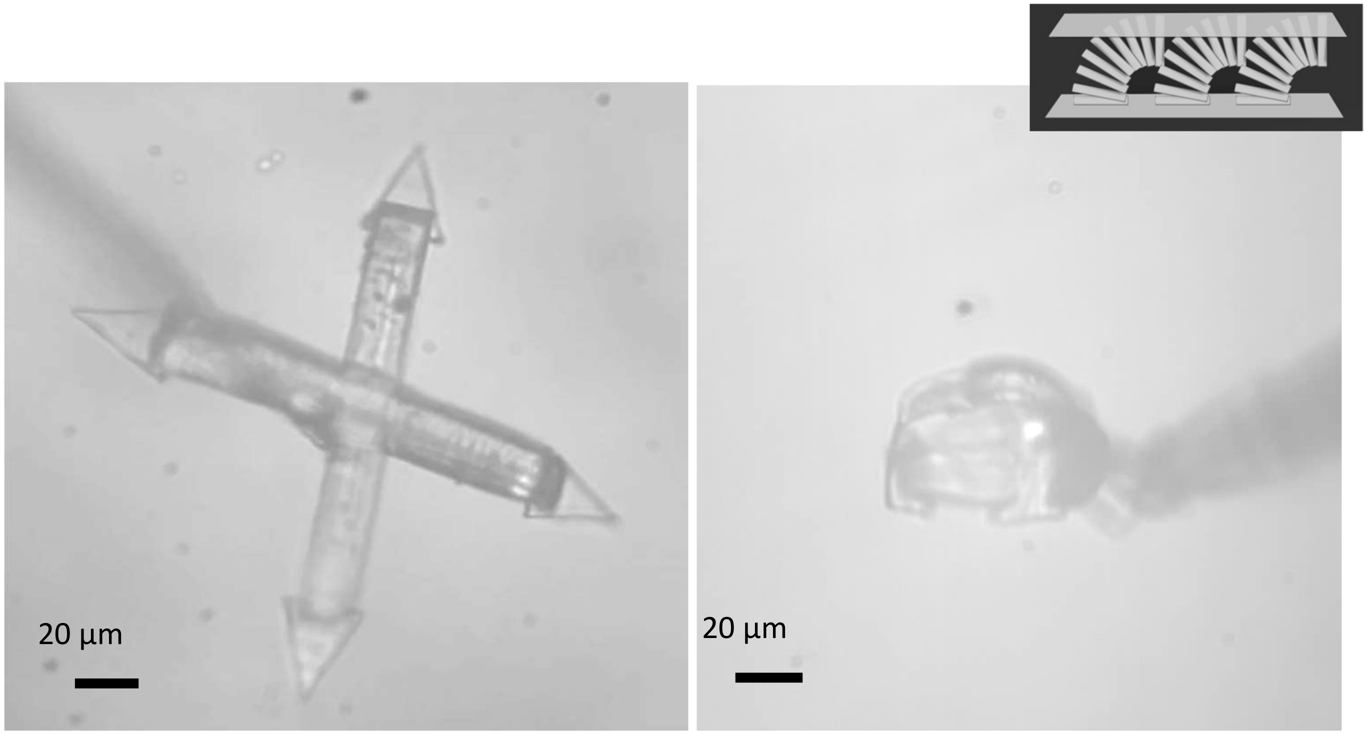


Microrobotics in dry environment: a micro-walker



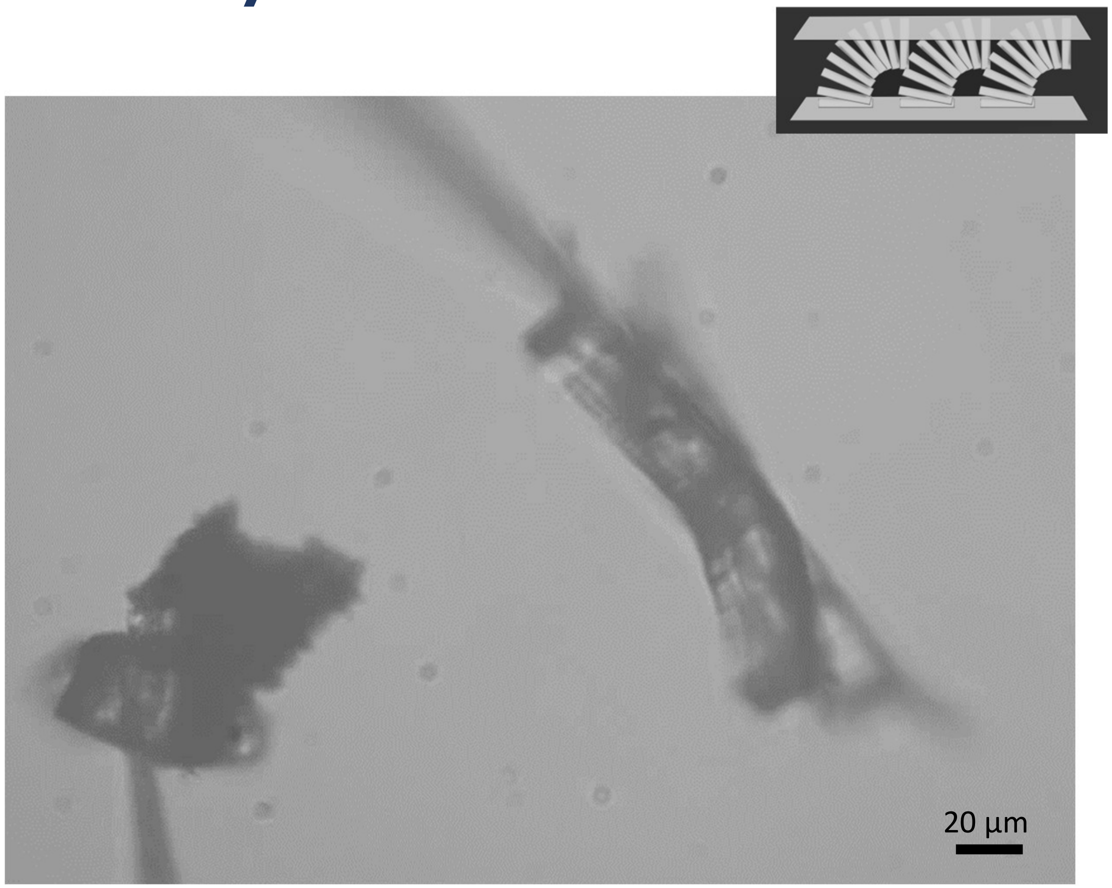
H. Zeng et al., *Adv. Mater.* **2015**, 27.26: 3883

Microrobotics in dry environment: a micro-hand



D. Martella, S. Nocentini et al., *Adv. Mater.* **2017**, *29.42: 1704047;*

Microrobotics in dry environment: a micro-hand



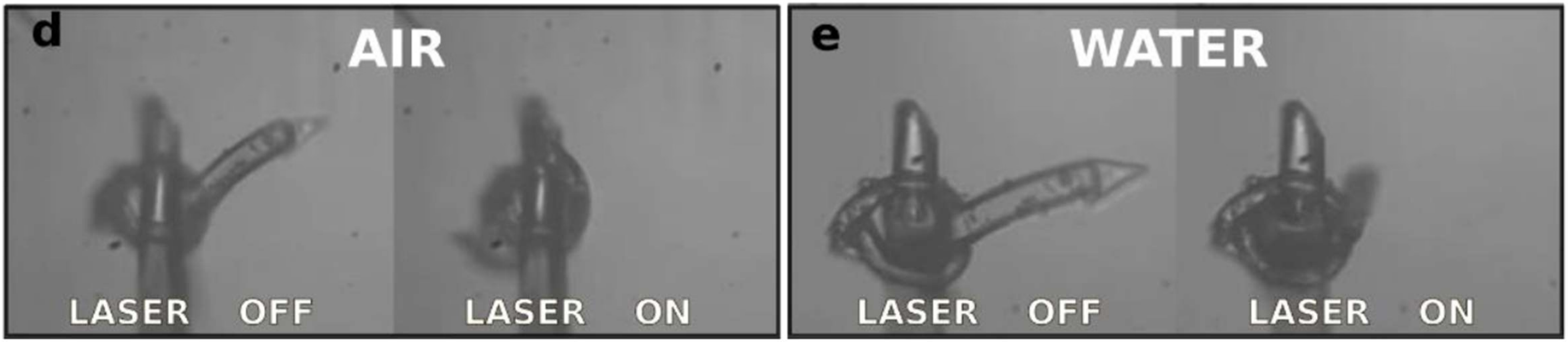
Laser intensity under activation
threshold: Autonoumous operation

D. Martella, S. Nocentini et al., *Adv. Mater.* **2017**, *29.42: 1704047;*

Microrobotics under-water: a micro-hand

σ_a=0.028 W/m*K

σ_w= 0.598 W/m*K at 20 °C



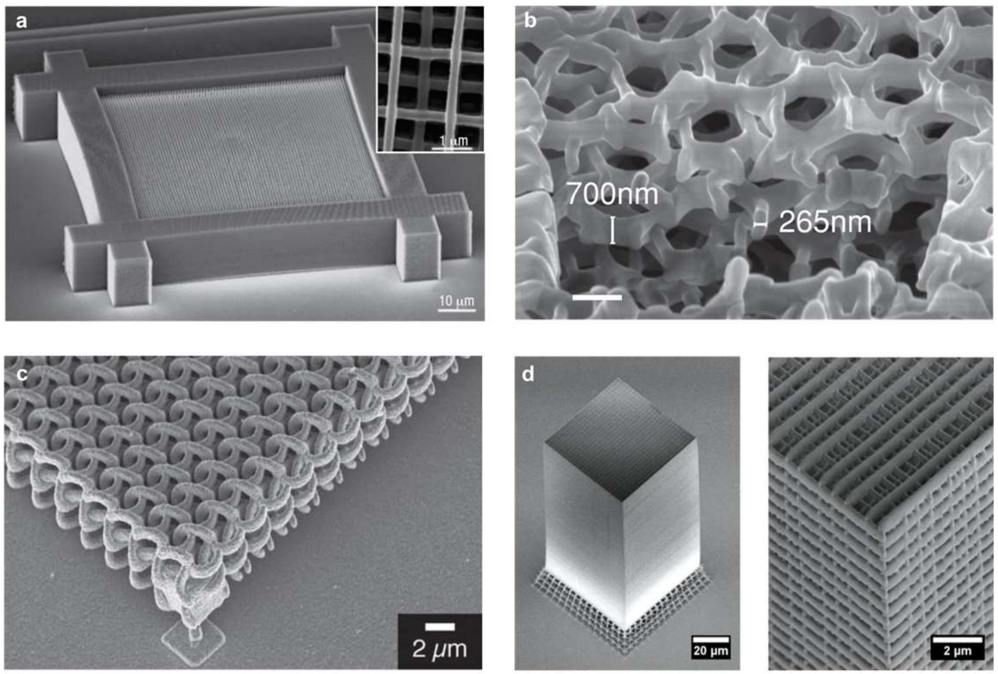
Activation Power : **30 mW** **150 mW**

D. Martella, S. Nocentini et al., *Adv. Mater.* **2017**, *29.42: 1704047;*

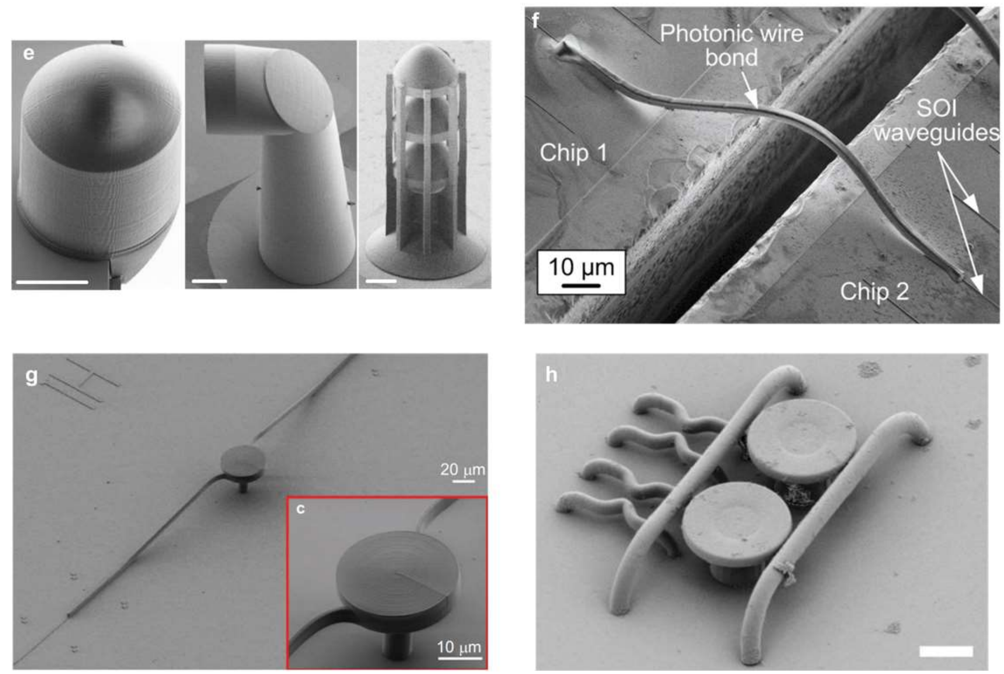
3D polymer photonics

Glassy resists

Ordered and disordered photonic crystals

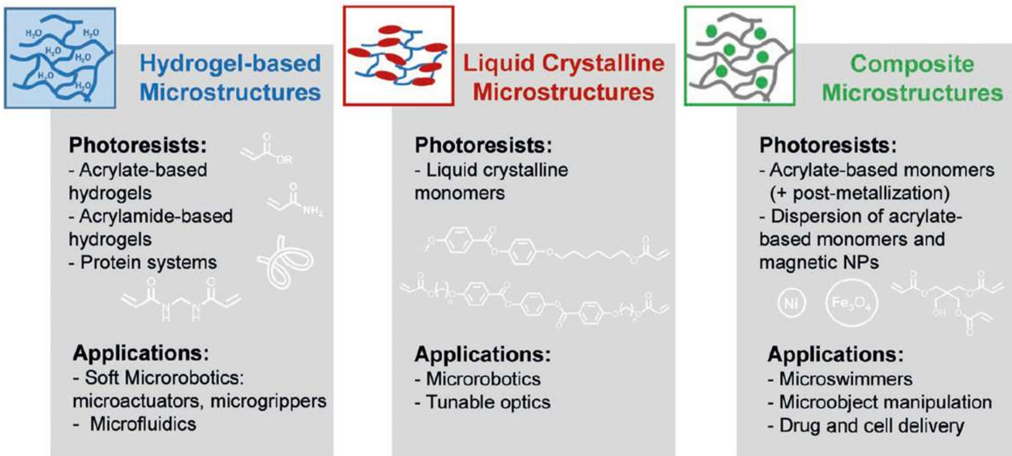


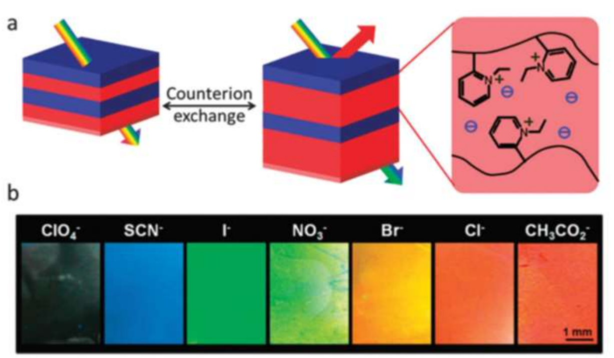
Optical and photonic components for integrated circuits



a) *Nat. Mater.* **2004**, *3*, 444. b) *Adv. Opt. Mater.* **2014**, *2*, 115. c) *Adv. Mater.* **2011**, *23*, 3018. d) *Adv. Opt. Mater.* **2014**, *2*, 226. e) *Nat Photonics* **2018**, *12*, 241. f) *Opt. Express* **2012**, *20*, 17667. g) *Light: Sci. Appl.* **2014**, *3*, e175. h) *Sci. Rep.* **2013**, *3*, 1577.

reconfigurable polymer photonics

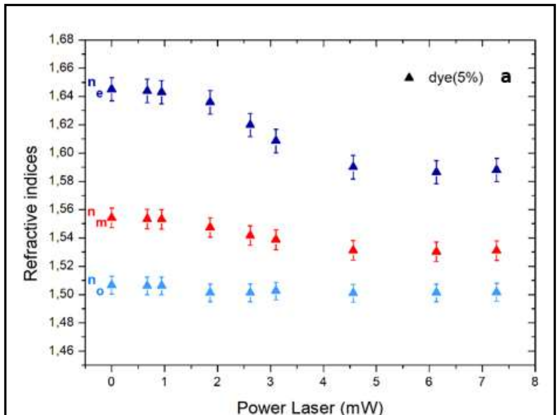




ACS Nano **2012**, 6, 8933.

Geometry or Refractive index

LCN:
Birefringence control
Reversible anisotropic shape change

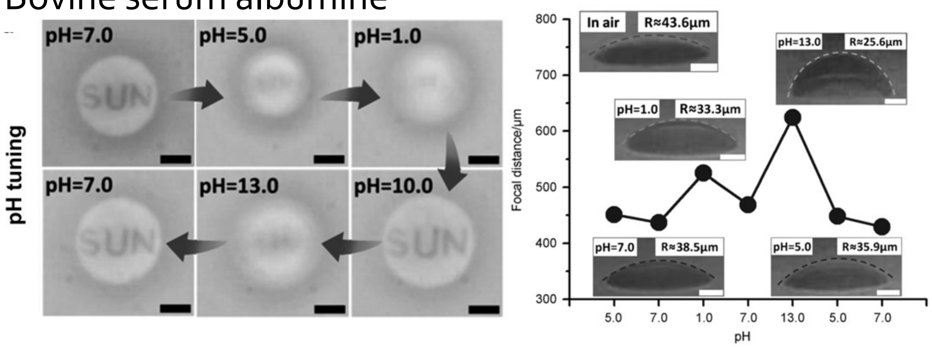


Spiegel, C. et al, (2020). 4D printing at the microscale. *Advanced Functional Materials*, *30*(26), 1907615.

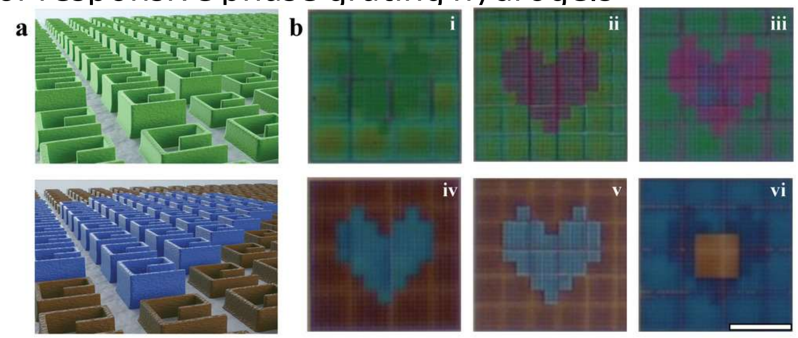
4D polymer photonics

Responsive resists

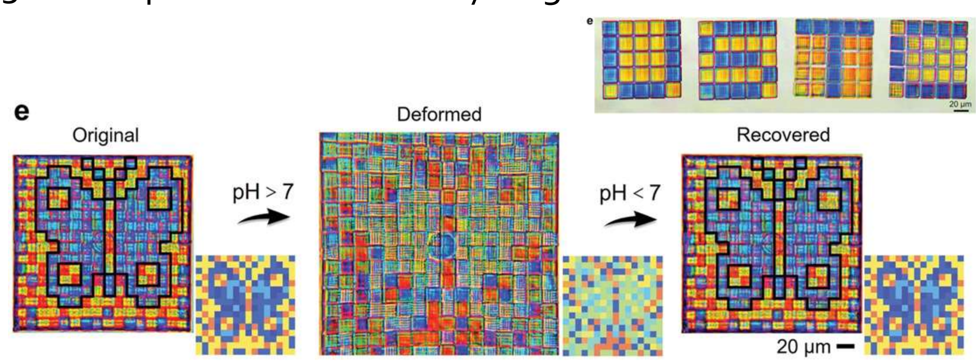
Bovine serum albumine[1]



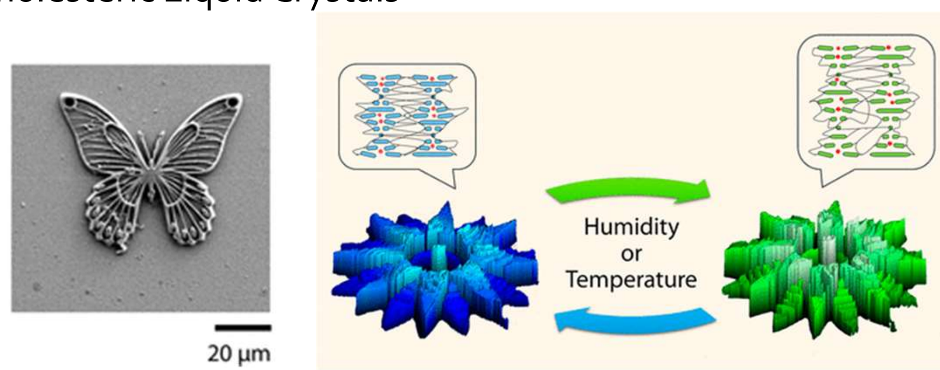
Vapour responsive phase grating hydrogels[2]



3D nanopatterned colored hydrogels[3]



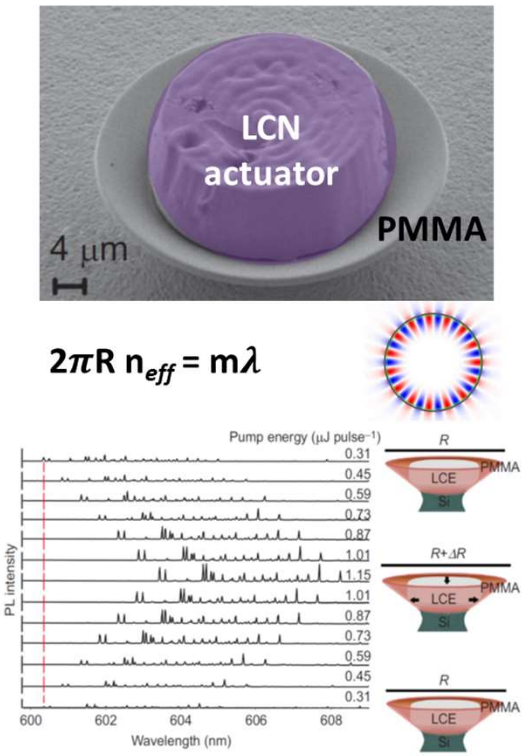
Cholesteric Liquid Crystals[4]



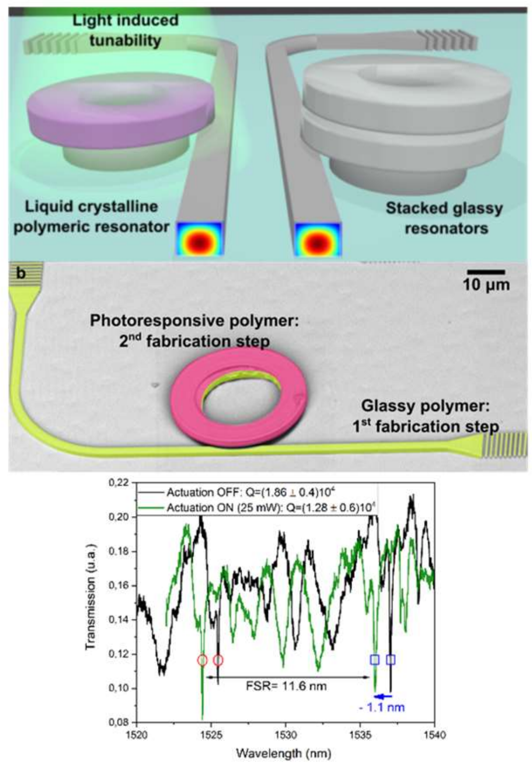
1. *Angew. Chem., Int. Ed.* **2012**, *51*, 1558. 2. *Adv. Funct. Mater.* ***2023***, 2211735. 3. *Small* ***2022***, p.2204630.
4. *ACS Nano* **2020**, 14, 8, 9832–9839.

liquid crystalline networks for photonics

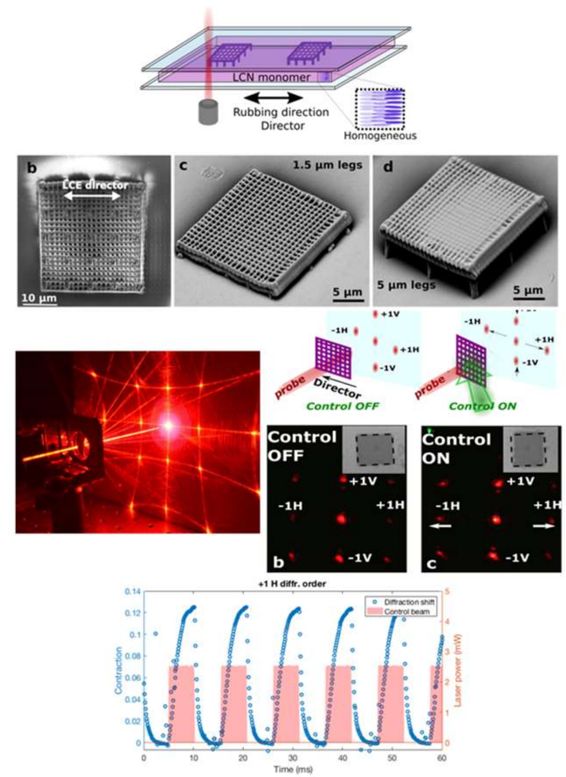
A light tunable microlaser



Optically controlled 3D photonic circuits



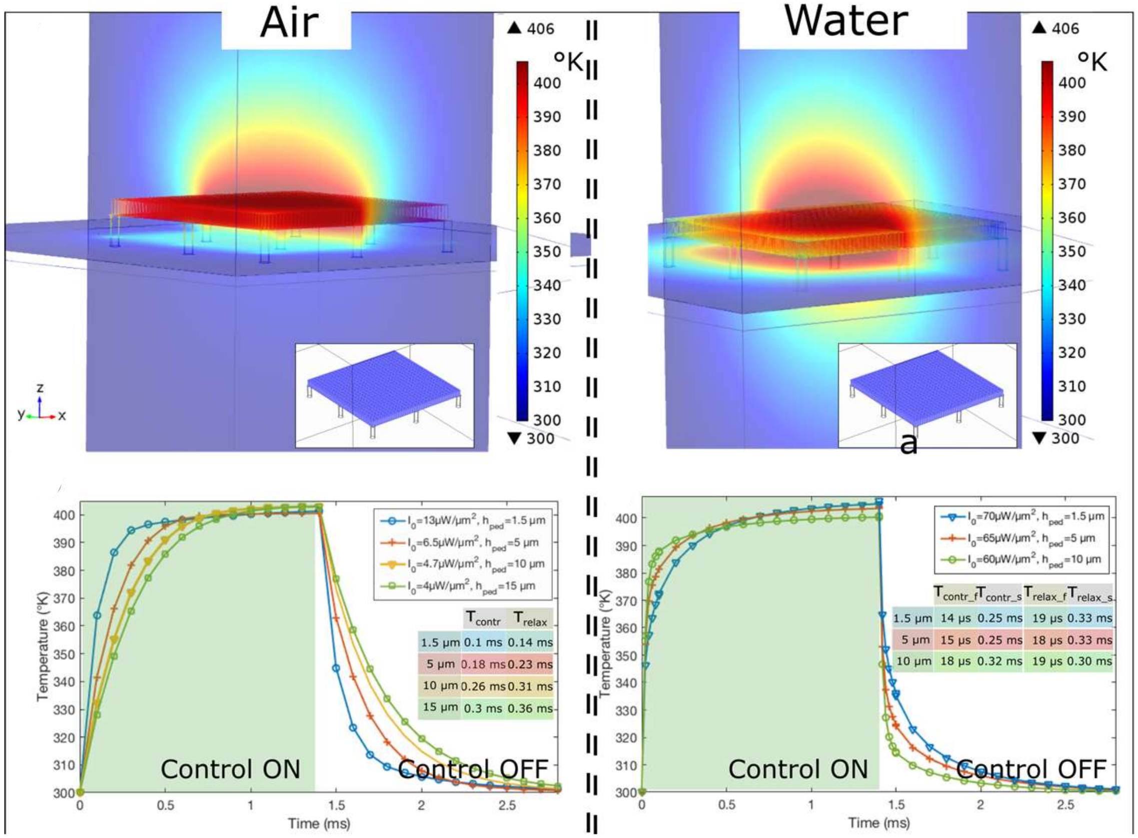
A light controlled beam steerer



Flatae A. M., et al. "*Light: Science & Applications* **2015,** 4.4, e282; Nocentini S., et al., *ACS Photonics* **2018** 5.8, 3222; Nocentini S., et al., *Advanced Optical Materials* **2018,** 6.15, 1800167

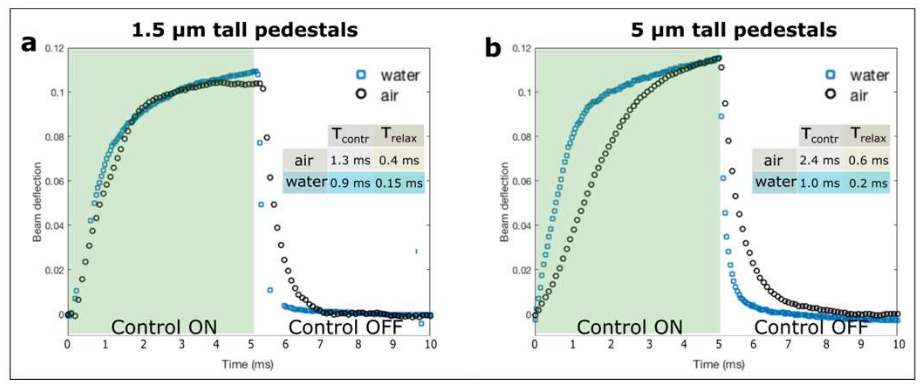
light controlled beam steering in air and under-water

Finite element method calculations



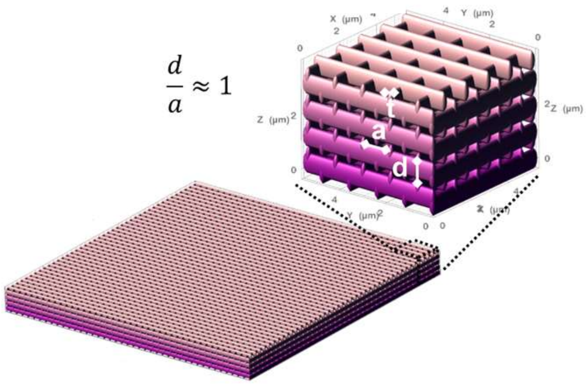
Pros (and cons) of LCN in water
- Sub-millisecond actuation
- Anisotropic deformation
- Smaller deformation

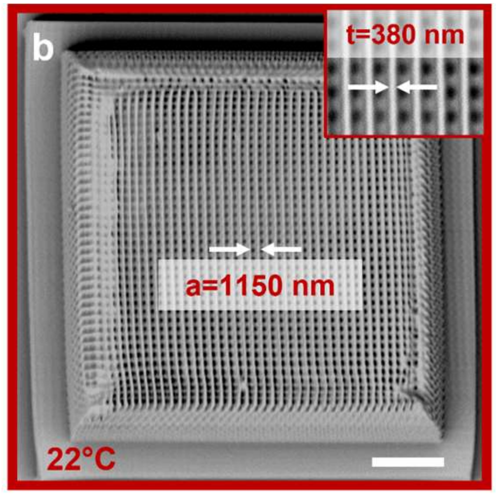
Experimental characterization



temperature responsive photonic crystals

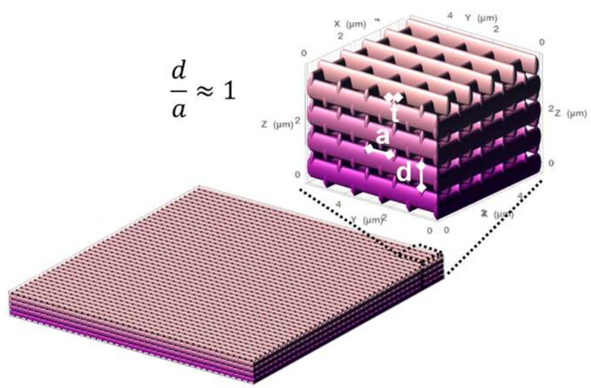
$$\frac{d}{a} \approx 1$$

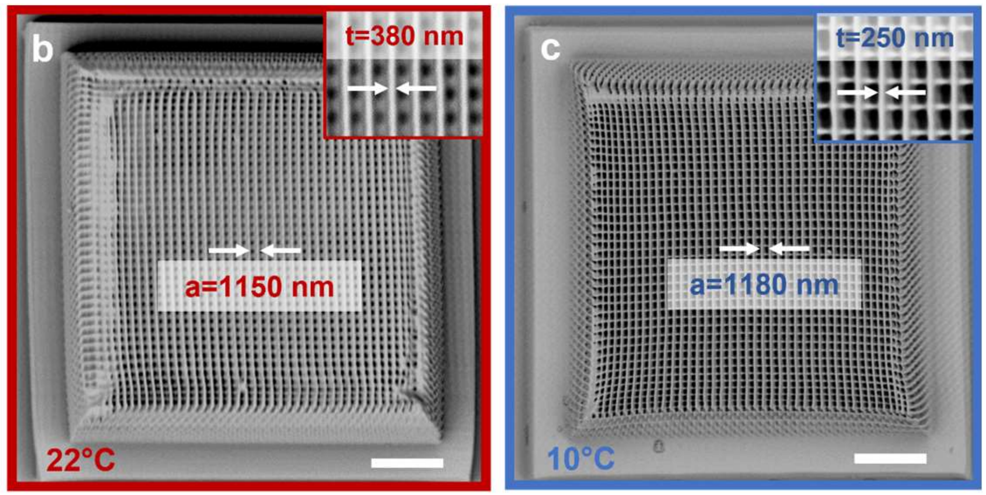


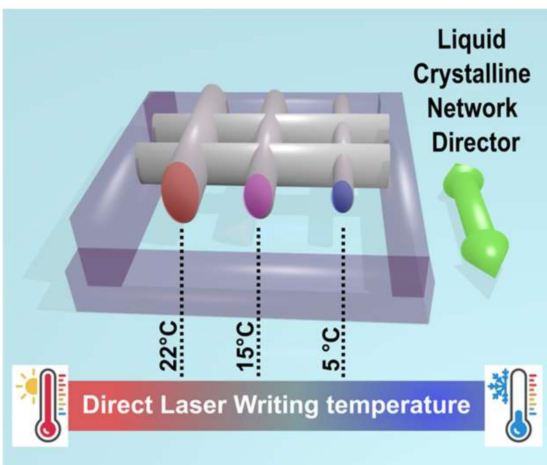


I. De Bellis, S. Nocentini, *et al.*, “Temperature Tunable 4D Polymeric Photonic Crystals.” *Adv. Funct. Mater*, 2213162, **2023**.

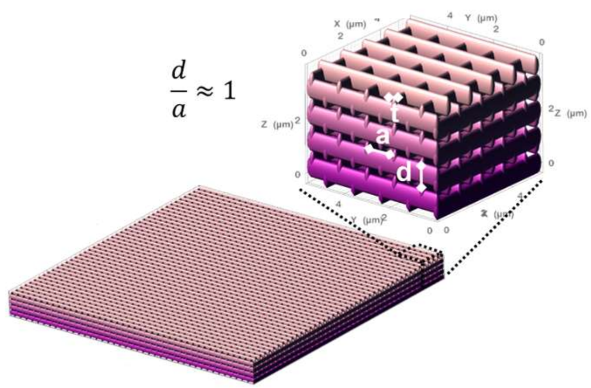
temperature responsive photonic crystals

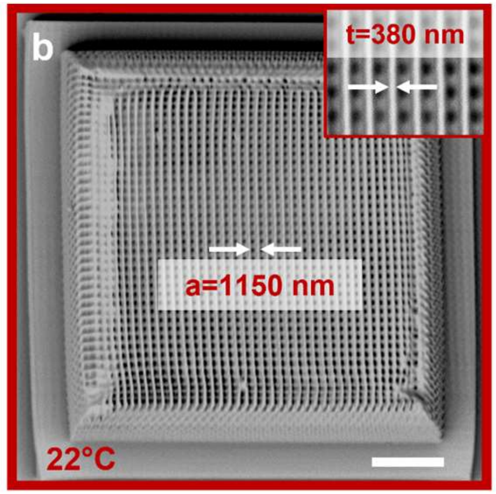


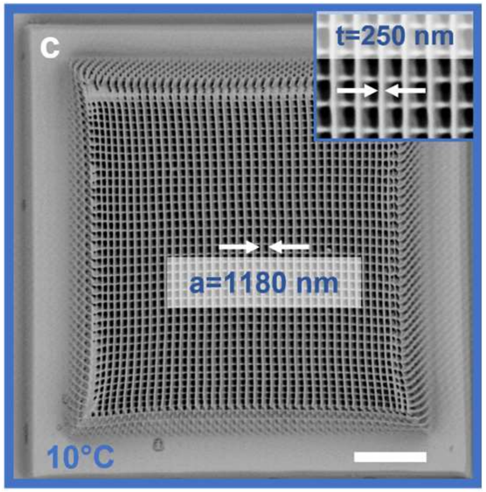


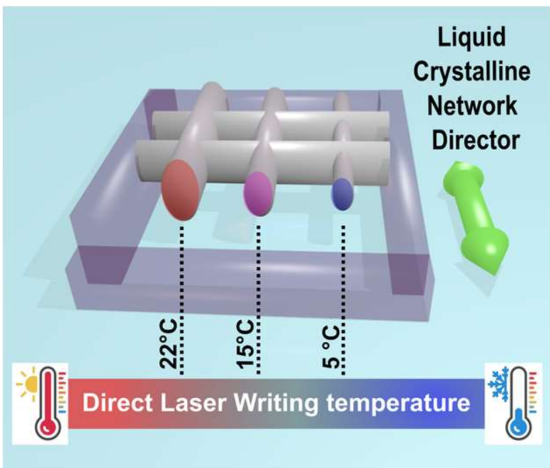


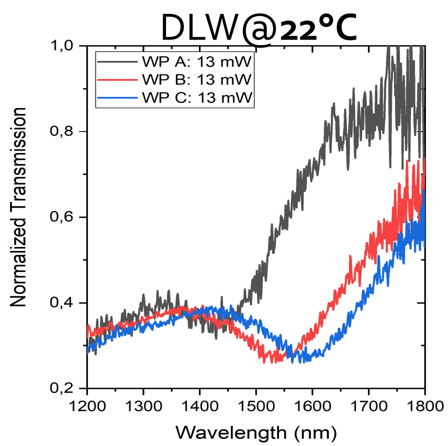
temperature responsive photonic crystals

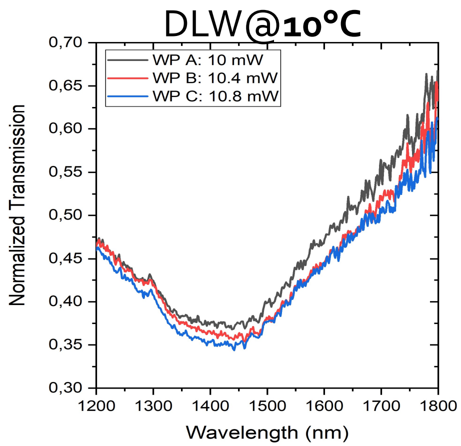






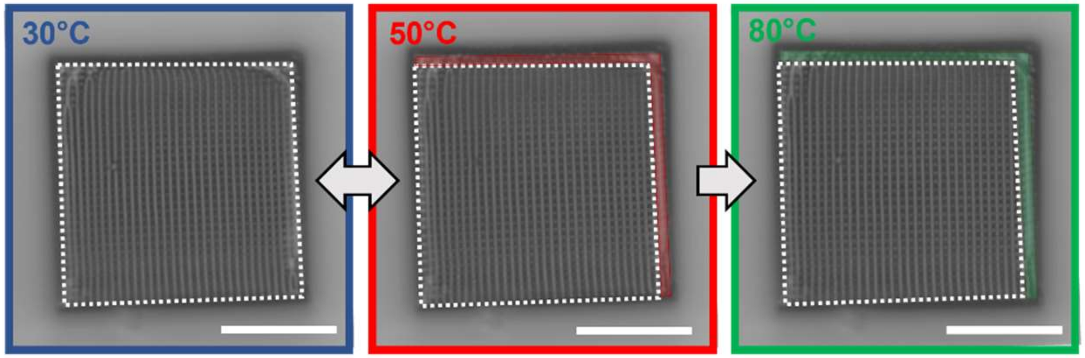


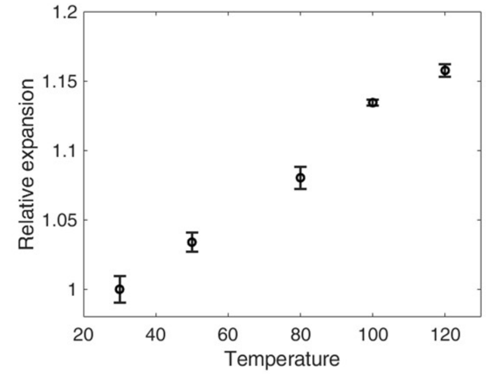


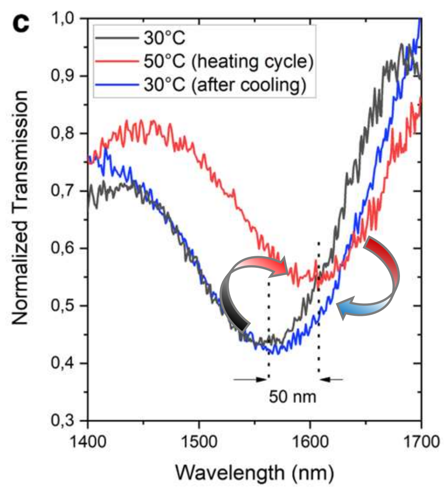


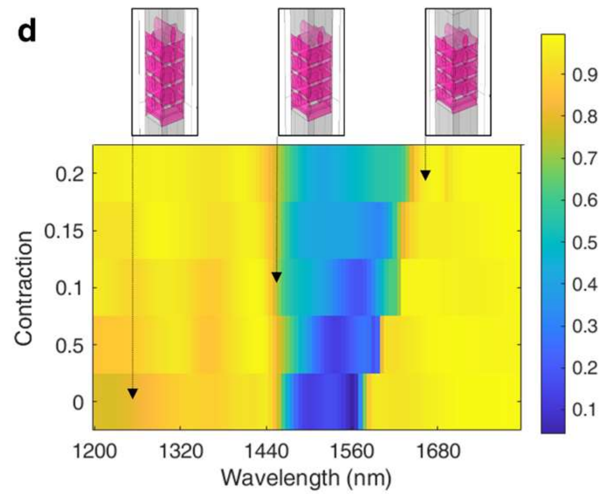
I. De Bellis, S. Nocentini, *et al.*, “Temperature Tunable 4D Polymeric Photonic Crystals.” *Adv. Funct. Mater*, 2213162, **2023**.

temperature responsive photonic crystals







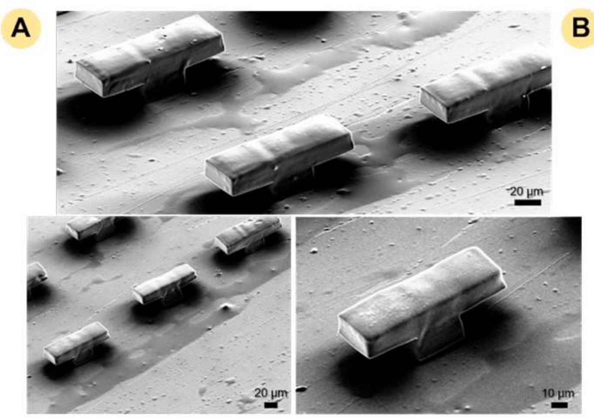


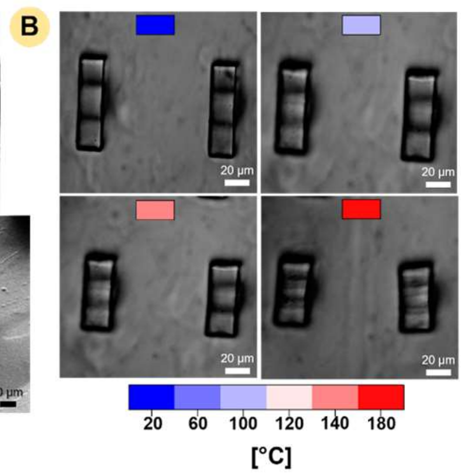
I. De Bellis, S. Nocentini, *et al.*, "Temperature Tunable 4D Polymeric Photonic Crystals." *Adv. Funct. Mater*, 2213162, **2023**.

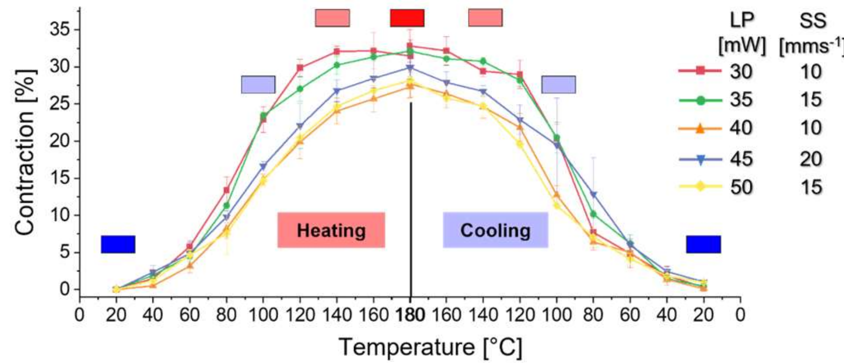
modulation of the LCN shape changing properties

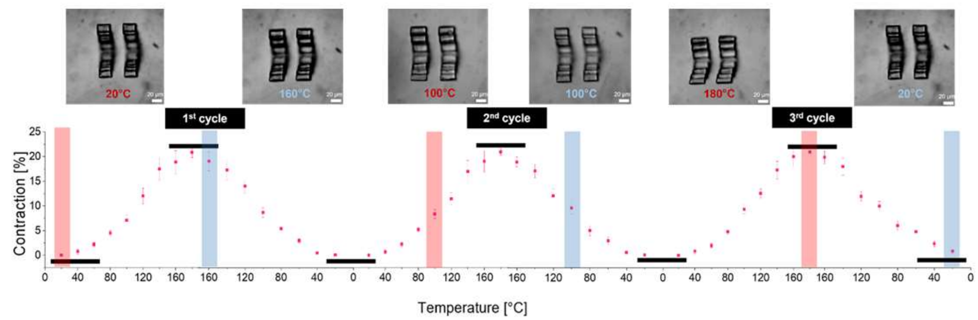
A. Chemical approach : changing the LC crosslinker substituent
B. Physical approach : tuning the lithographic parameters (laser power, scanning speed), "grey-scale" approach

GOAL : Active elements with different deformations (under a constant stimulus) using a single LCN formulation

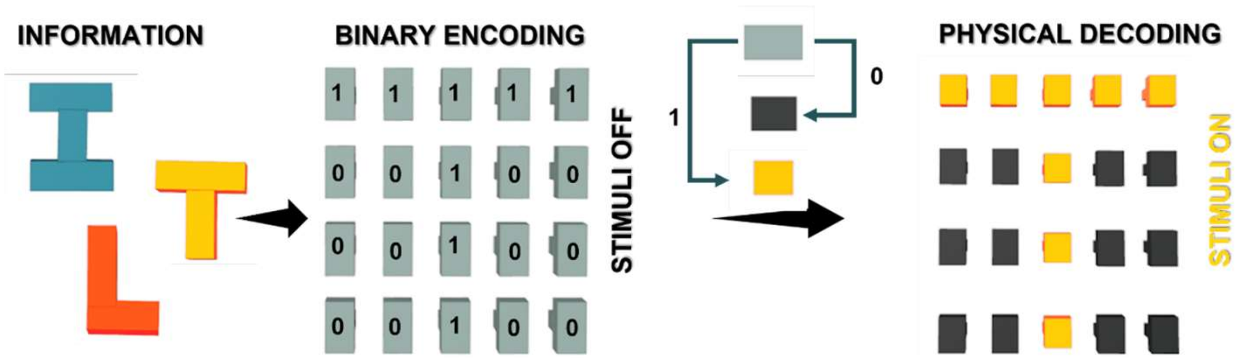




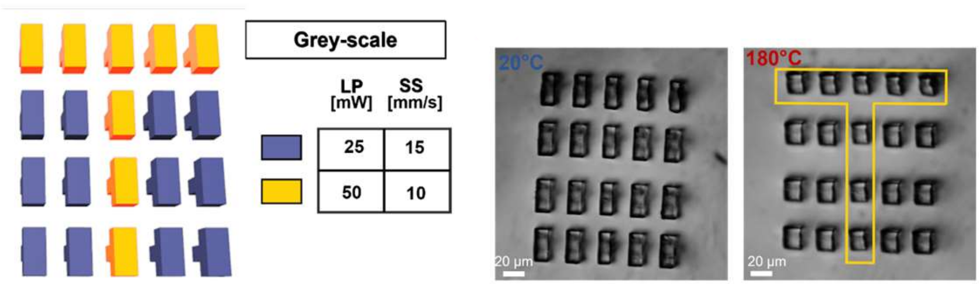




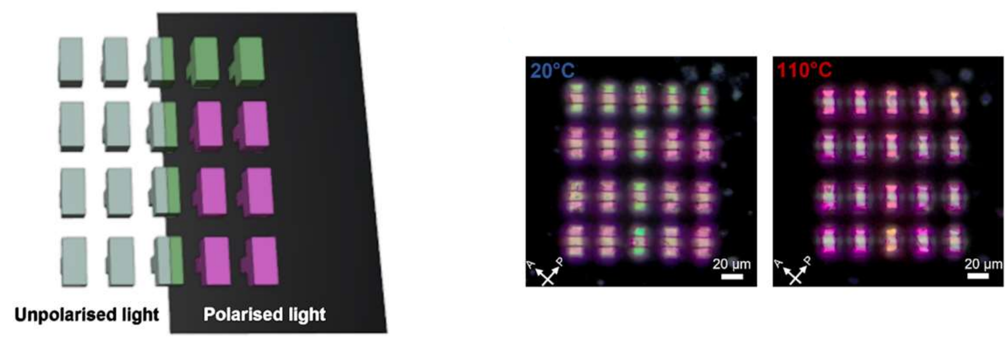
modulation of the LCN shape changing properties



Temperature decoding



Polarized light + temperature decoding



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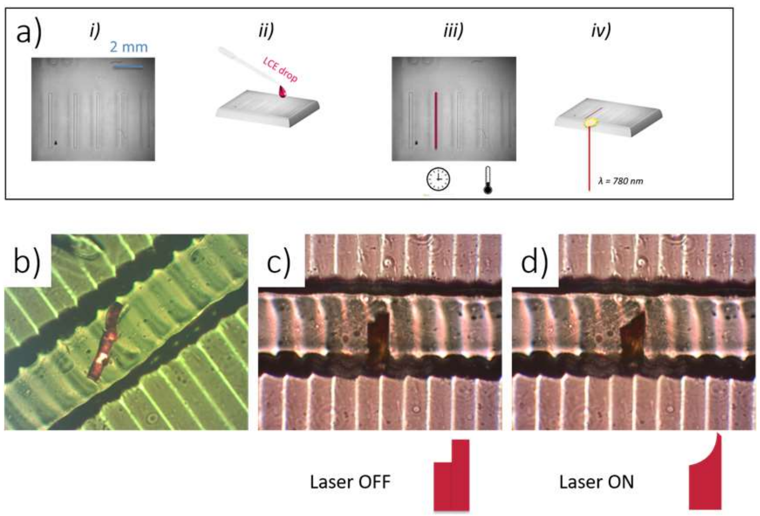

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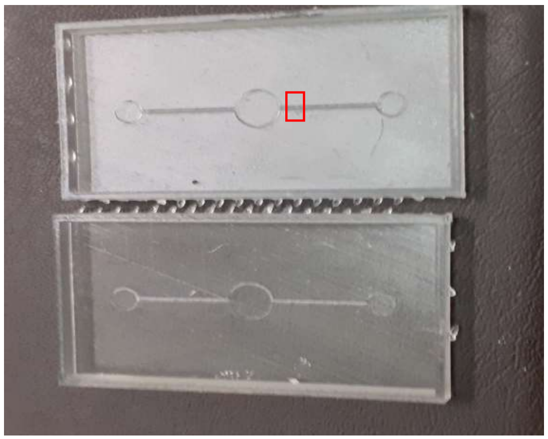
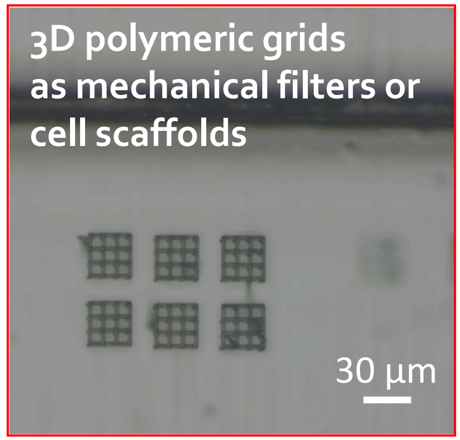
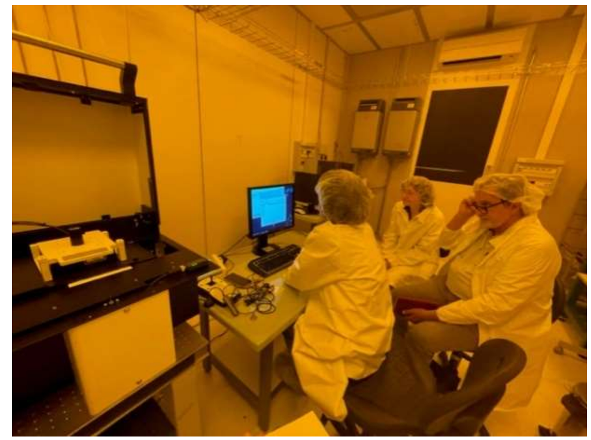
Integration of active and passive 3D microstructures in microfluidic circuits







A. Kovacevic, S. Savic and C. Credi

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Shape-changing microstructures for multifunctional microfluidics

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Thank you