



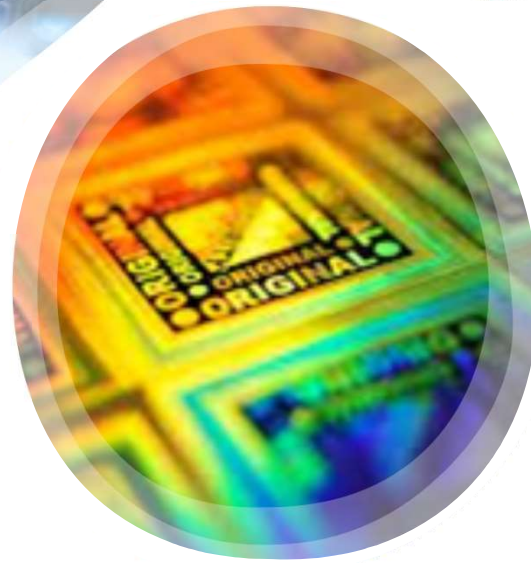
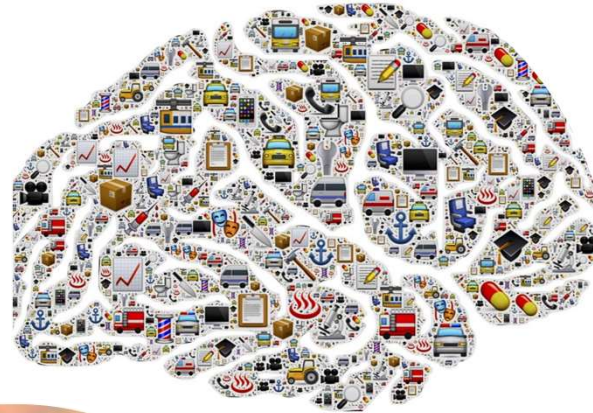
The hidden value of responsive materials

Sara Nocentini,

S. Donato, D. Martella, C. Parmeggiani, D. S. Wiersma, F. Riboli

nocentini@lens.unifi.it; s.nocentini@inrim.it

Kopaonik, 17th Photonics Workshop 11 March 2024

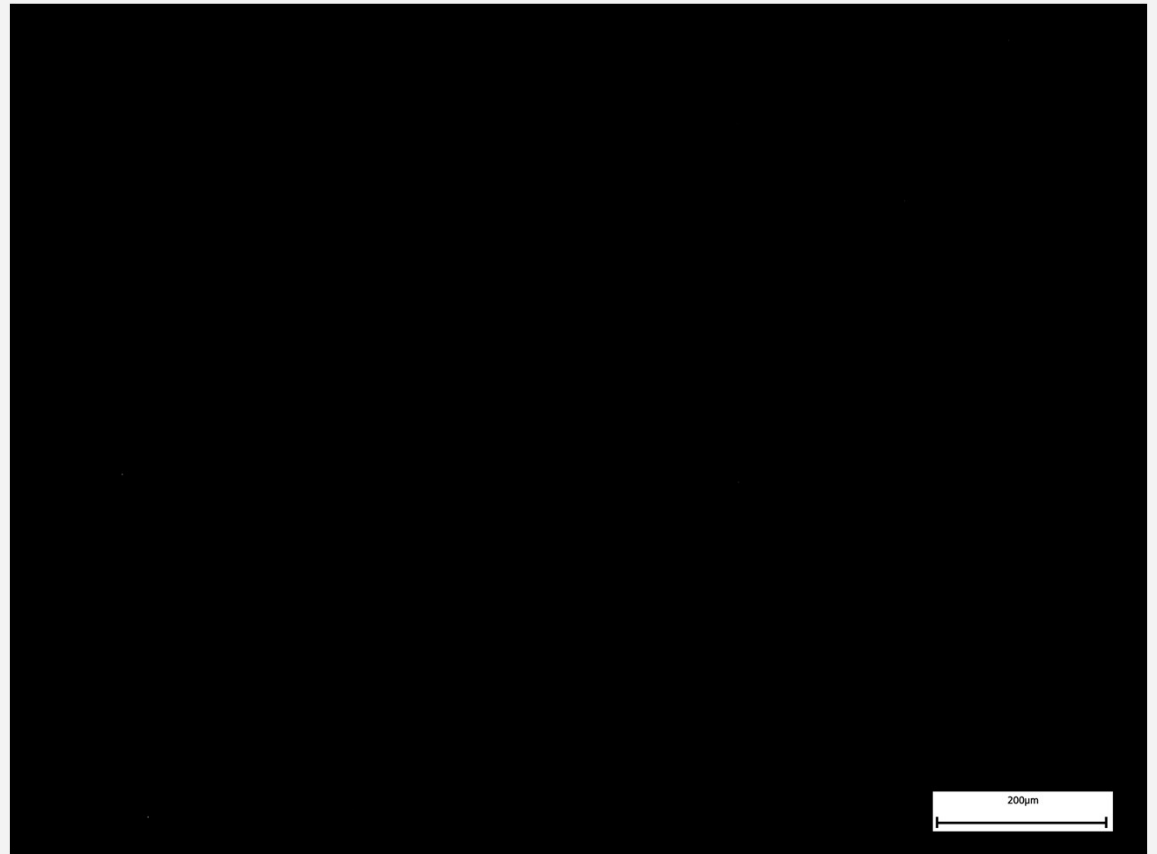
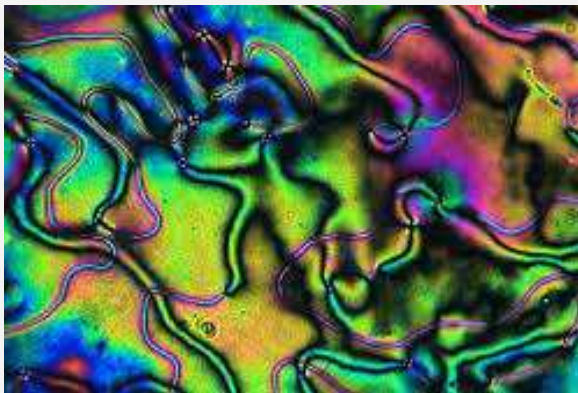
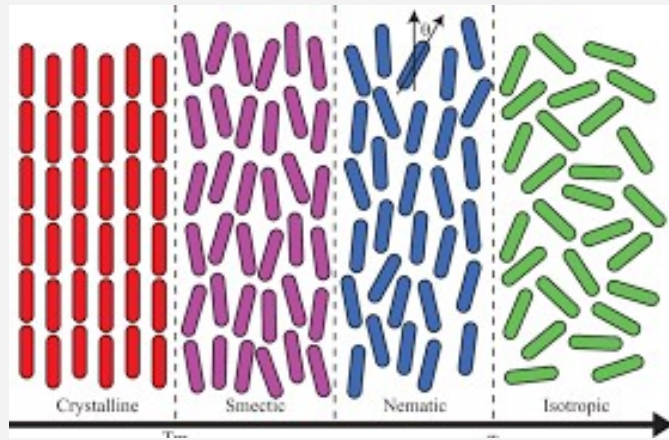


Encoding, storing, and retrieving information

Anticounterfeiting and Authentication

The role of responsive materials

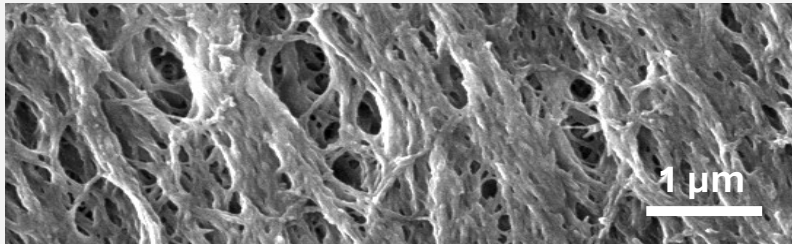
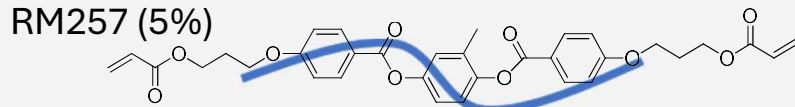
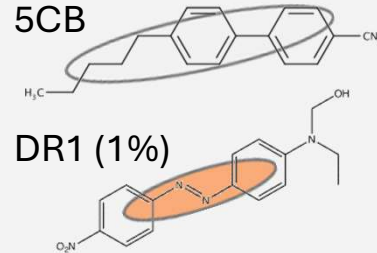
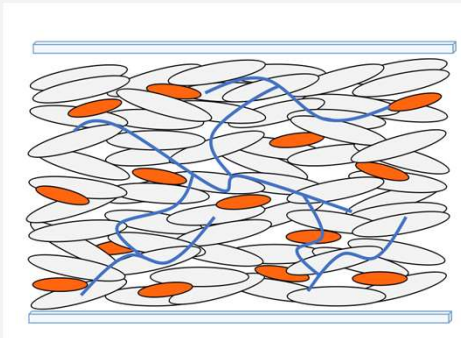
LIQUID CRYSTALS



The role of responsive materials

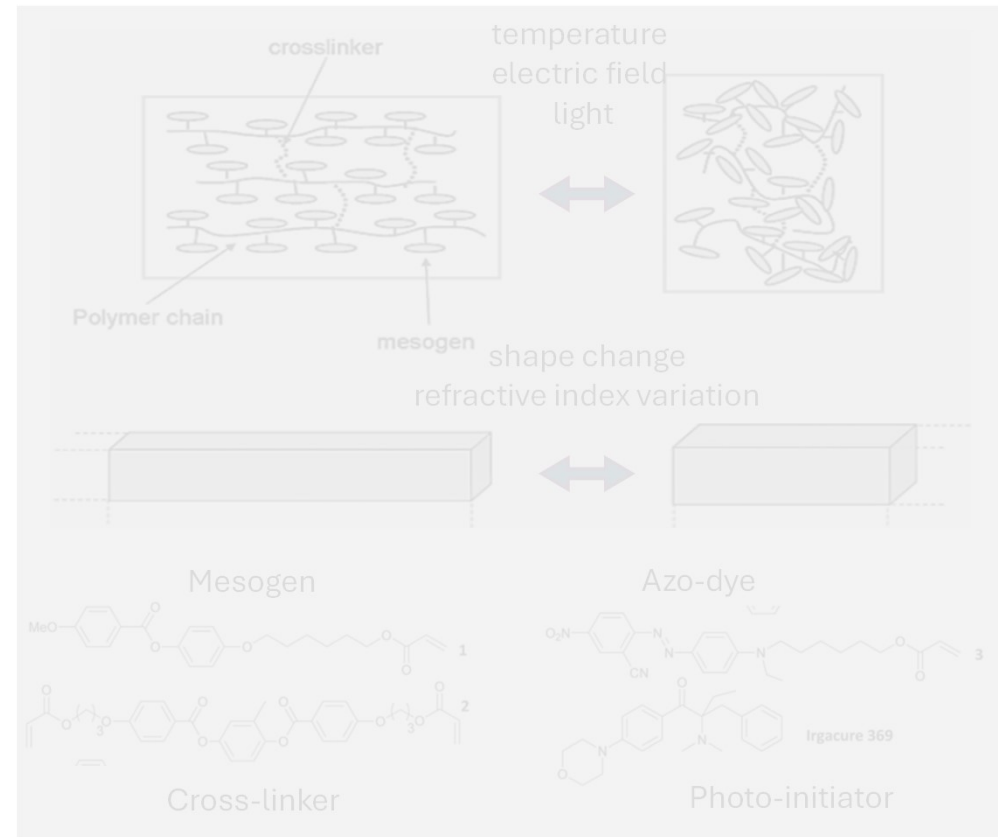
Reversible tunable birefringence

POLYMER-STABILIZED LIQUID CRYSTALS

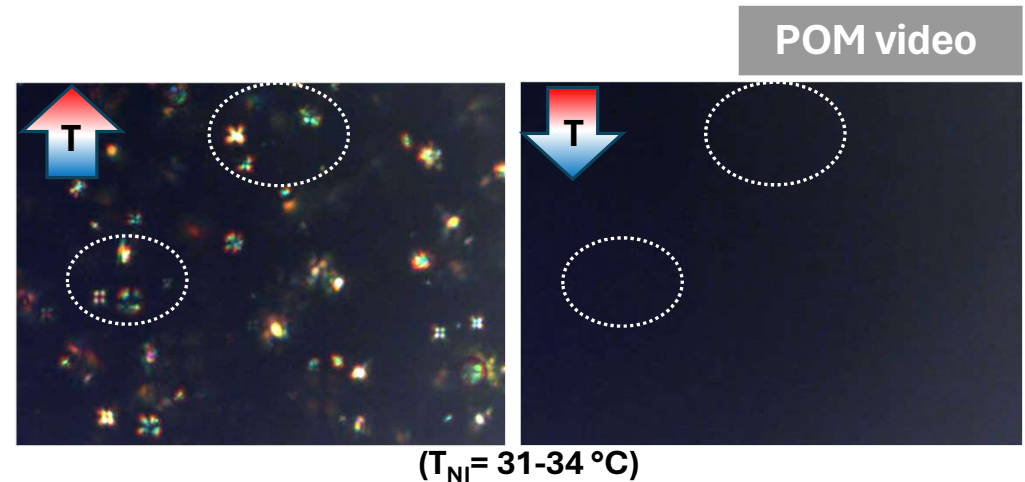
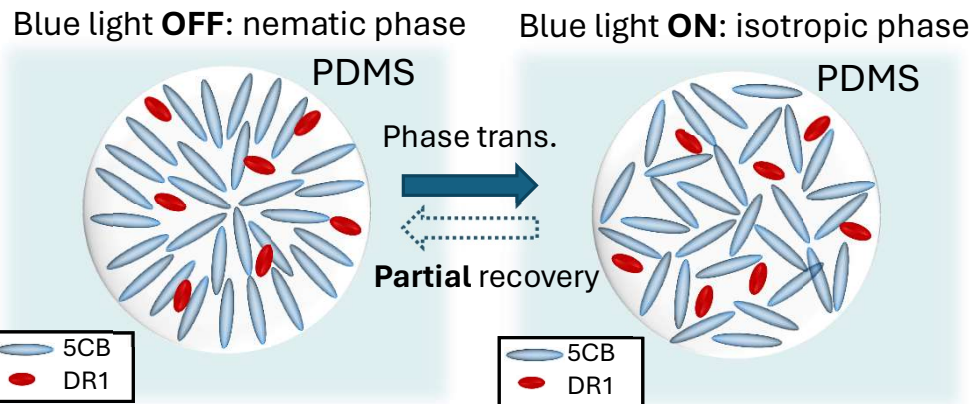
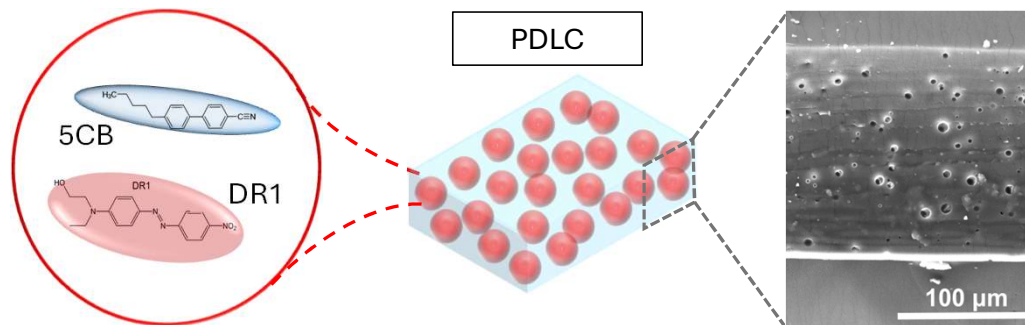


Shape-changing behavior

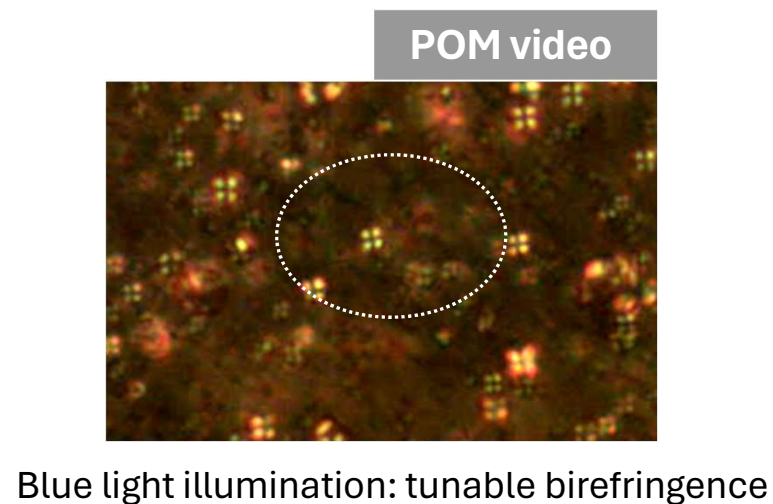
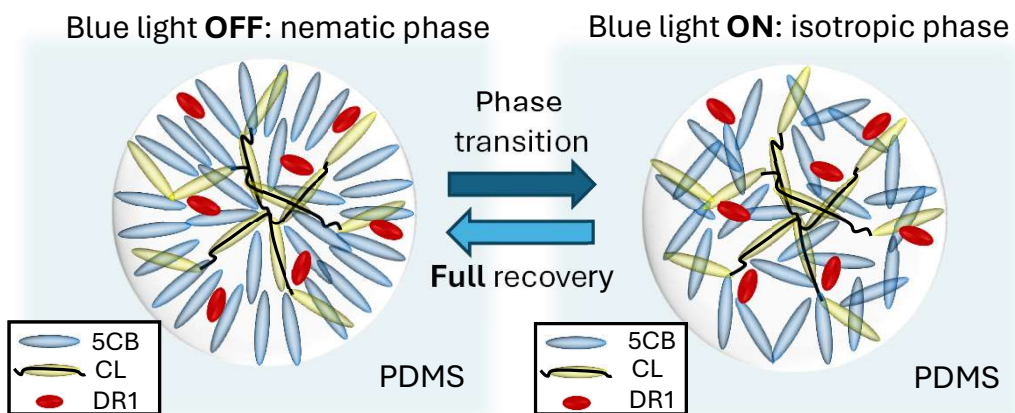
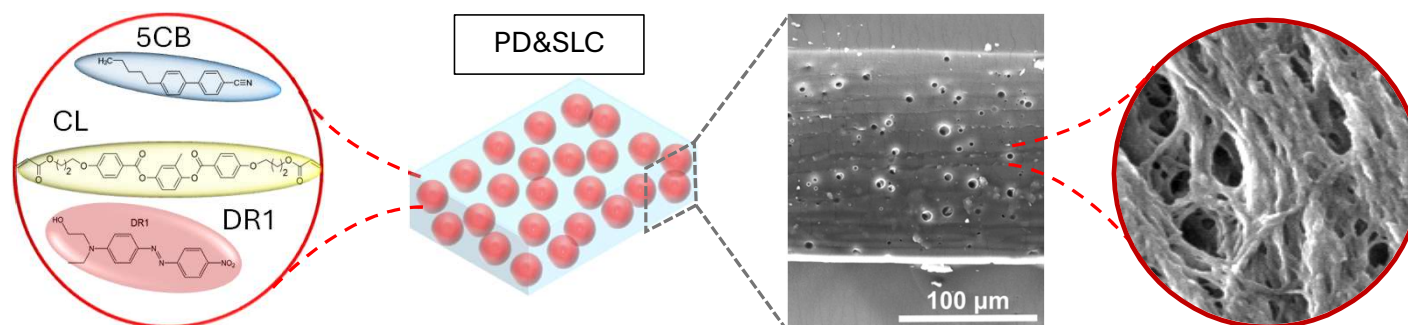
LIQUID CRYSTALLINE NETWORK



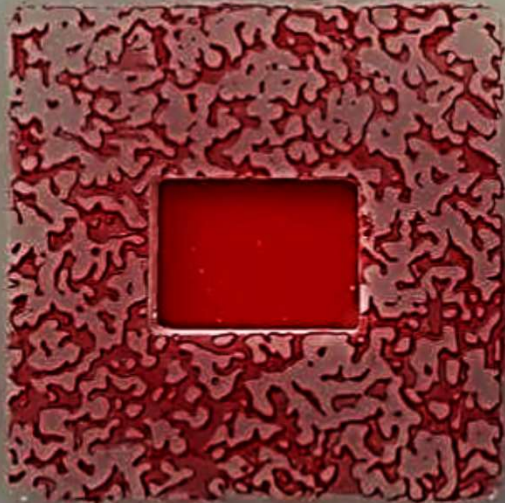
Polymer dispersed ~~and stabilized~~ liquid crystals



Polymer dispersed and stabilized liquid crystals



HPUF

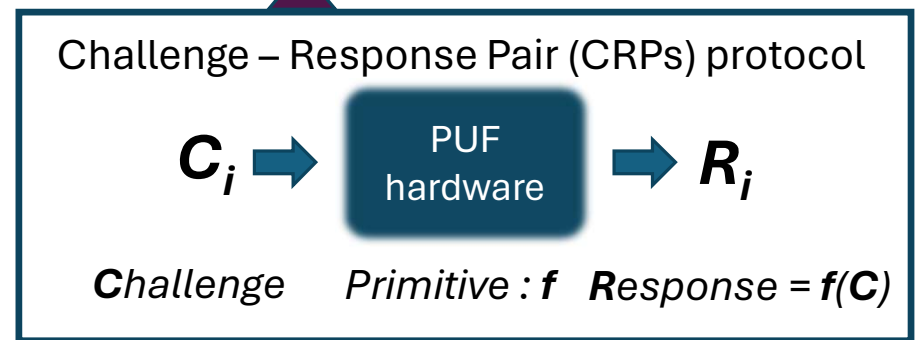
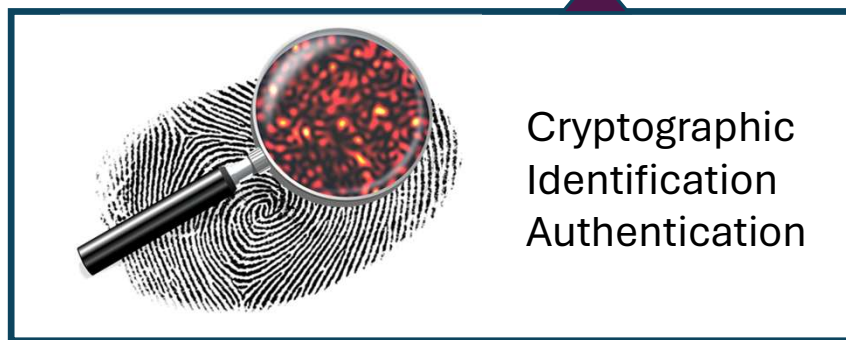


Ada Lovelace

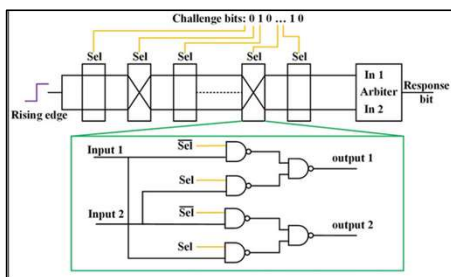
Physical Unclonable Functions (PUFs)

device with inherent randomness introduced during manufacturing as a unique 'fingerprint'

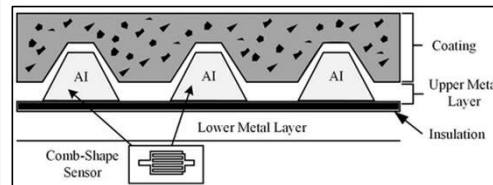
Unclonable, unpredictable but deterministic



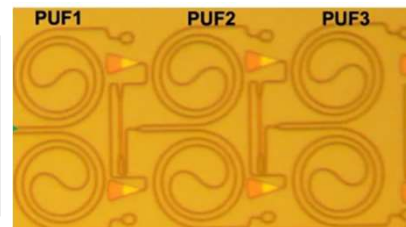
Electronic PUFs



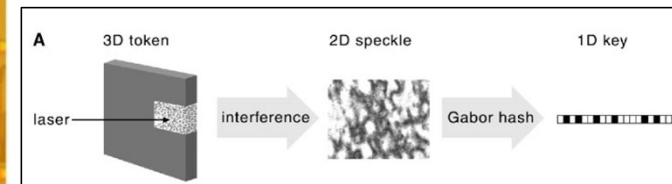
Coating PUFs



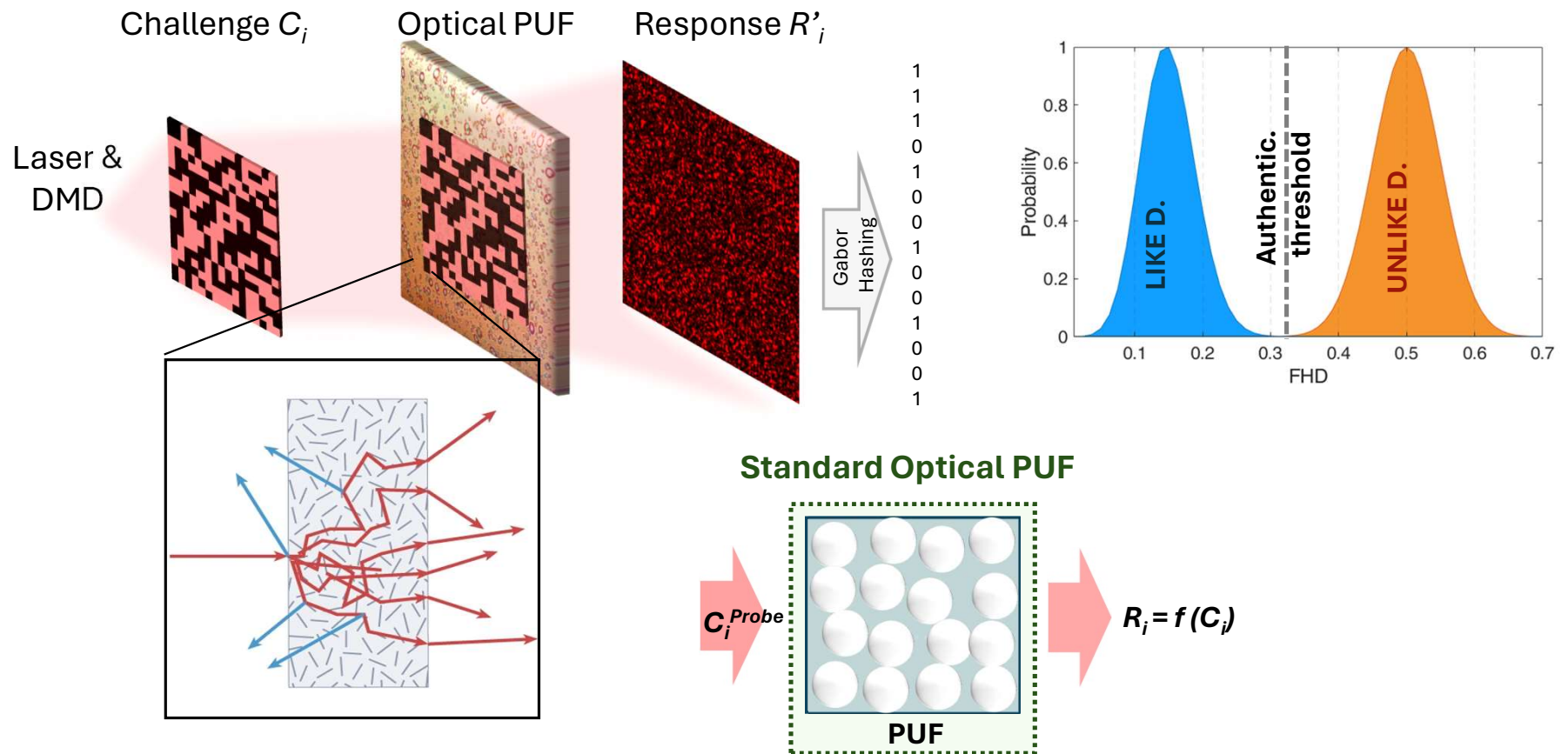
Silicon optical PUFs



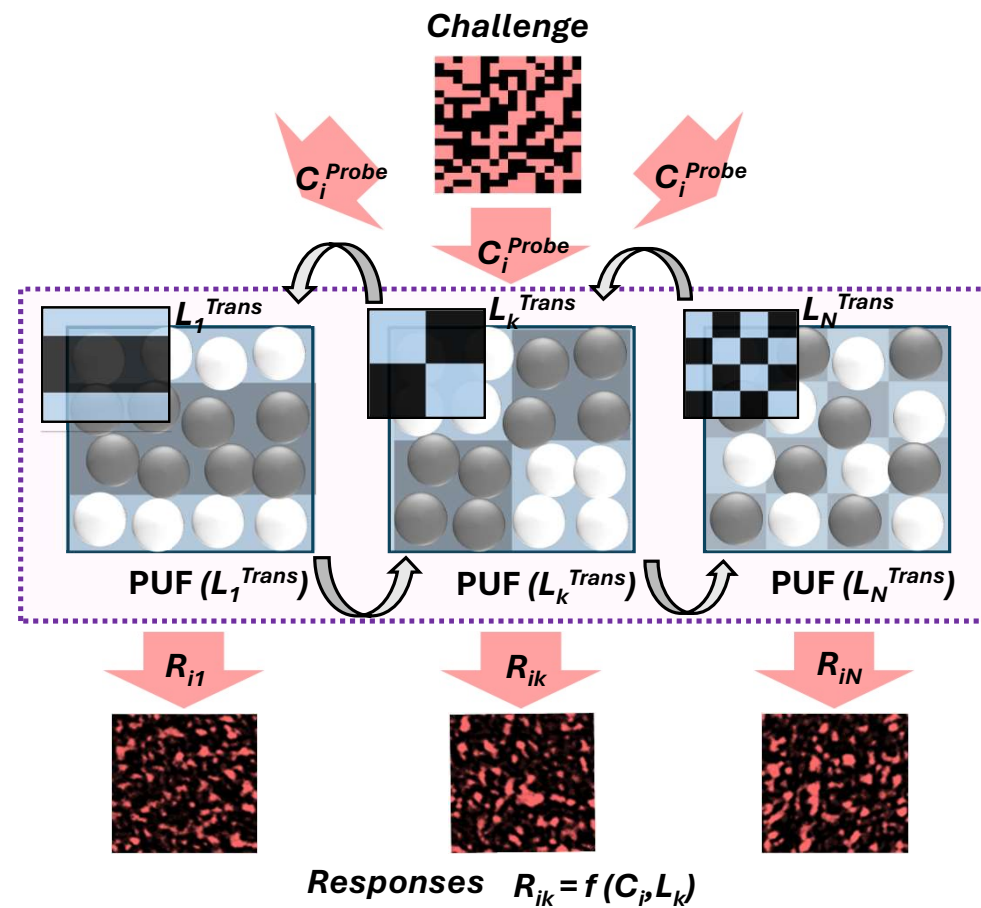
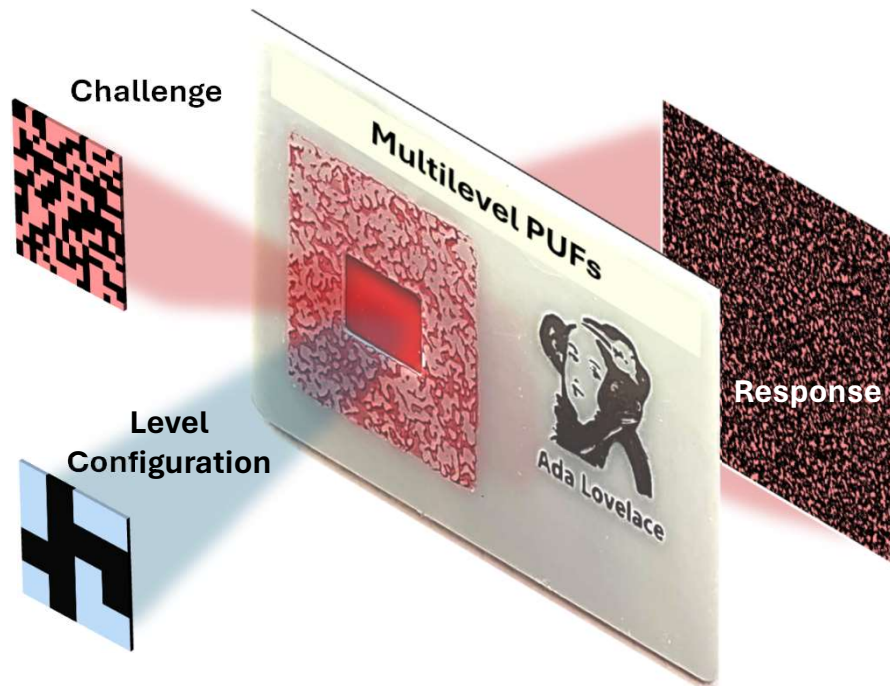
Optical PUFs (since 2002)



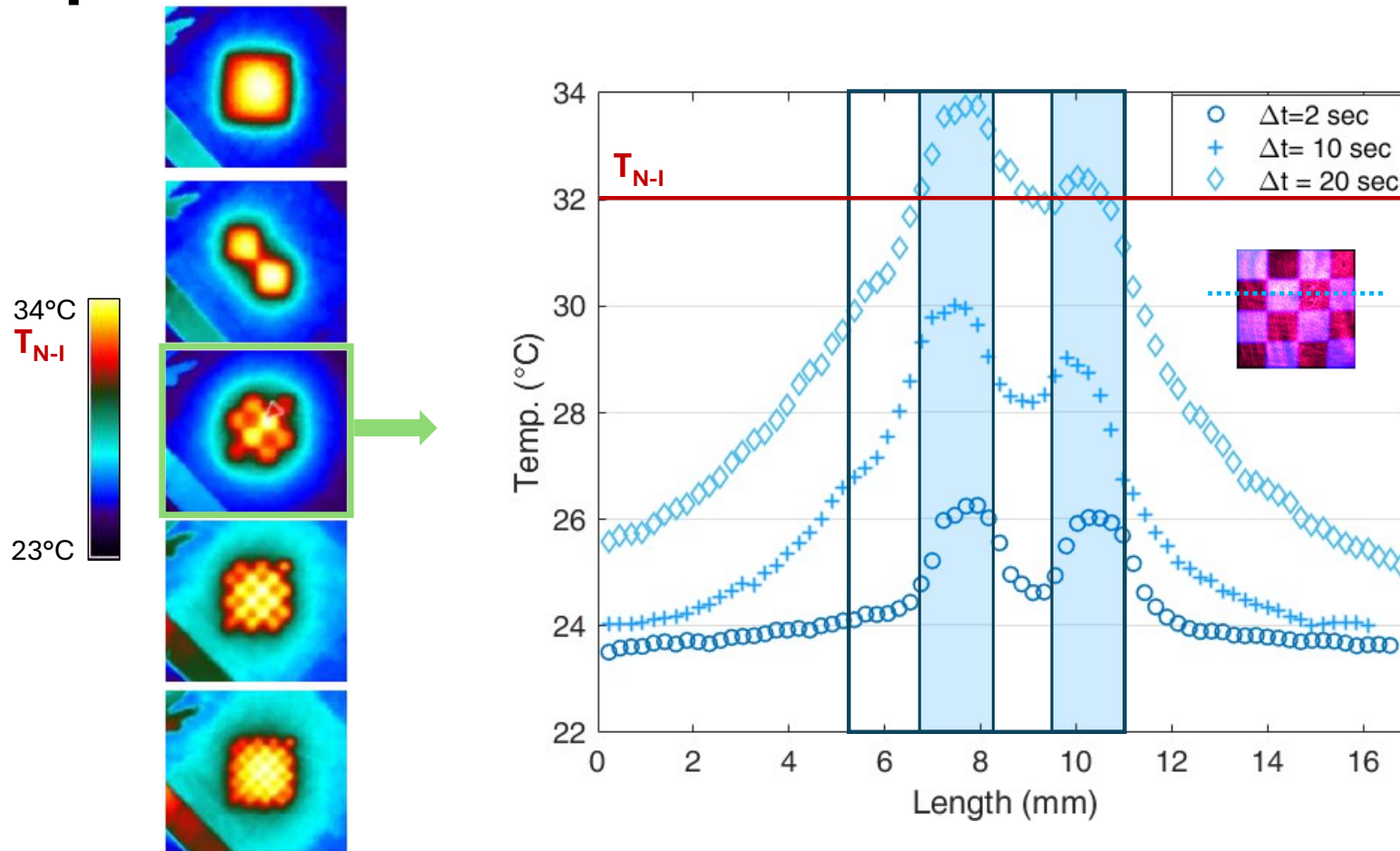
Optical Physical Unclonable Functions (OPUFs)



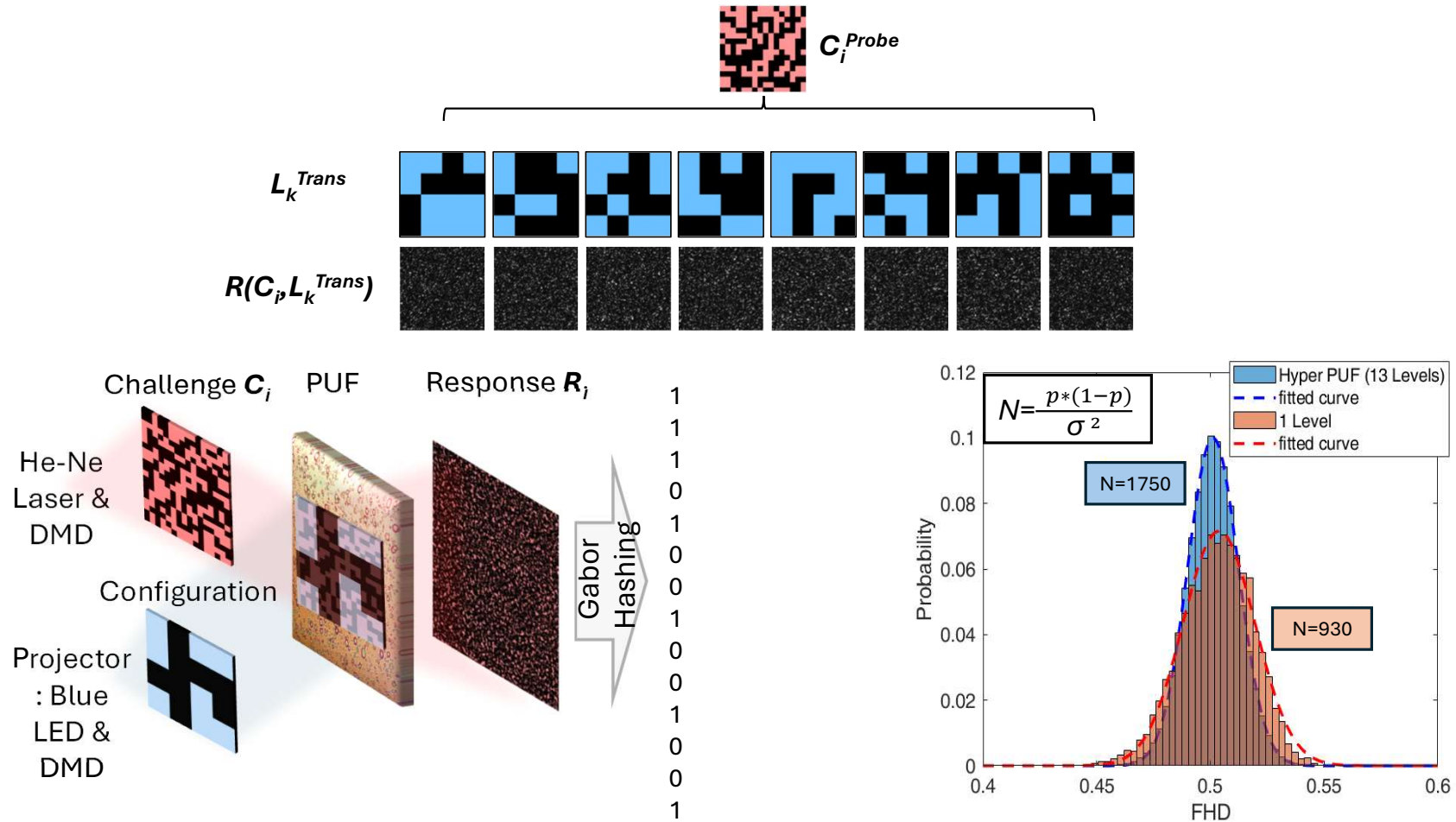
All-optical multilevel PUFs



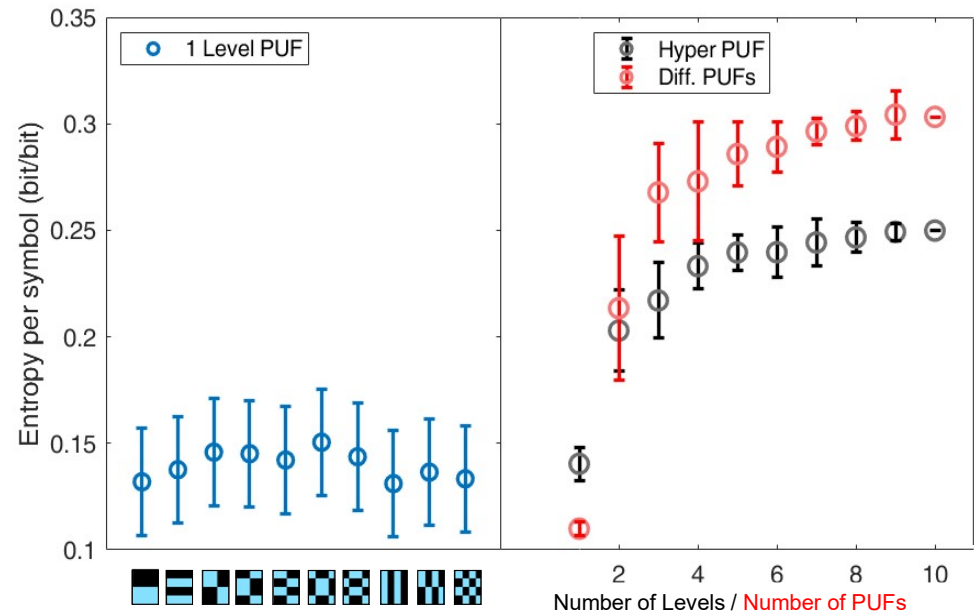
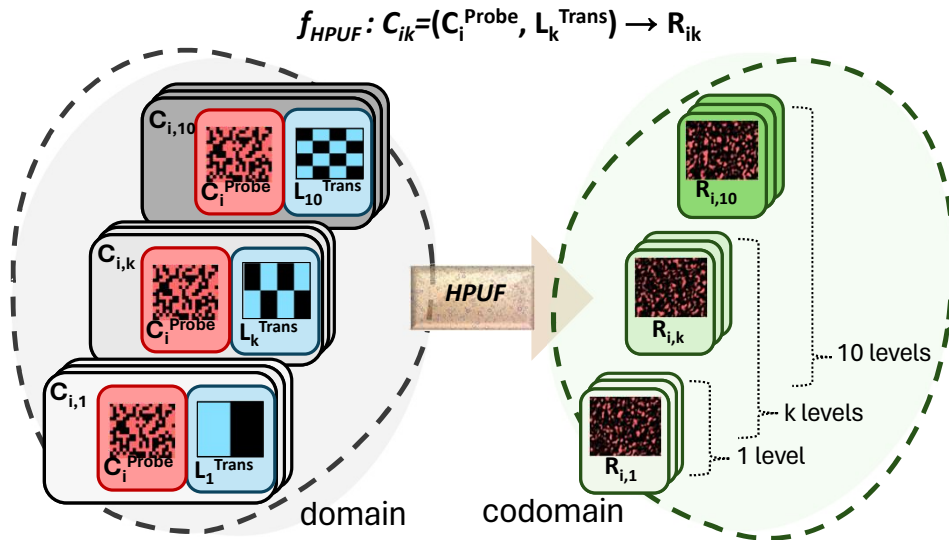
All-optical multilevel PUFs



All-optical multilevel PUFs

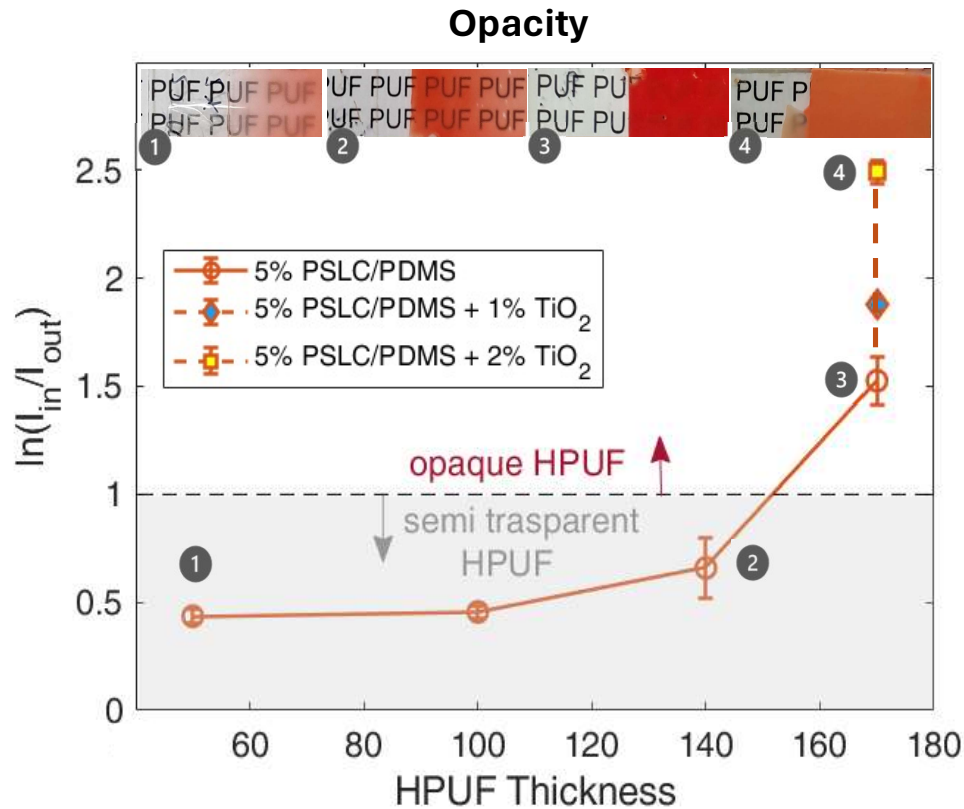


All-optical multilevel PUFs: Higher security



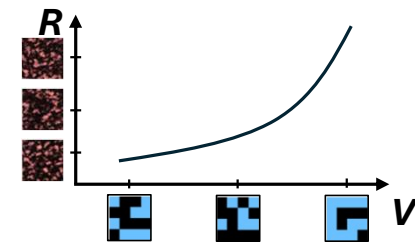
Extract all the information physically encoded in the hardware thanks to the reversible reconfiguration of the PD&SLC

All-optical multilevel PUFs: Applications

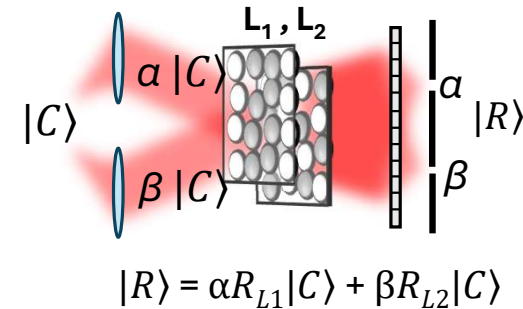


Nonlinear PUFs (OP>1)

$$R = VC + V^2C + V^3C + \dots$$



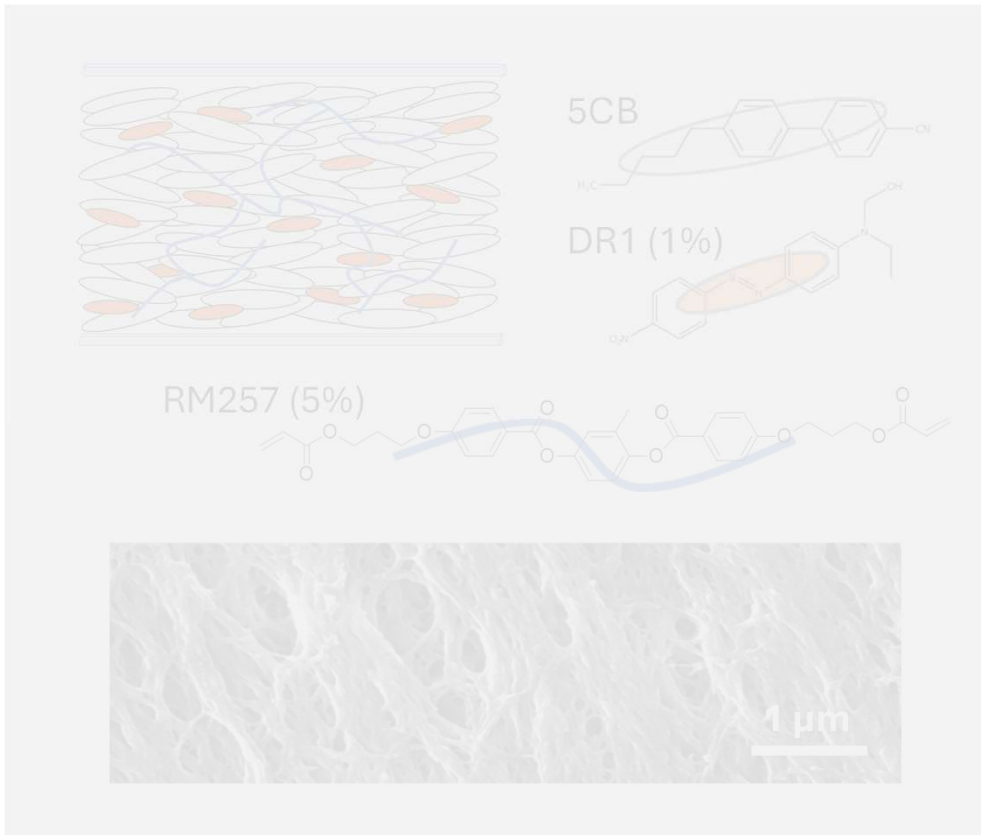
Quantum data authentication (OP<1)



The role of responsive materials

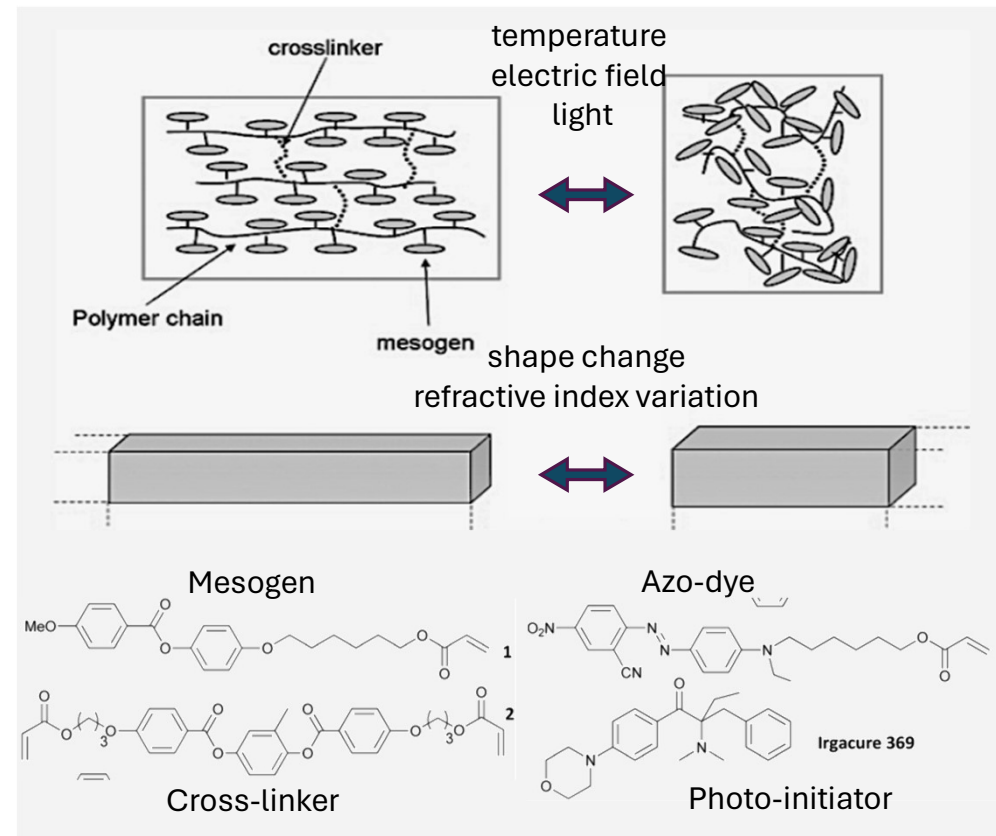
Reversible tunable birefringence

POLYMER-STABILIZED LIQUID CRYSTALS

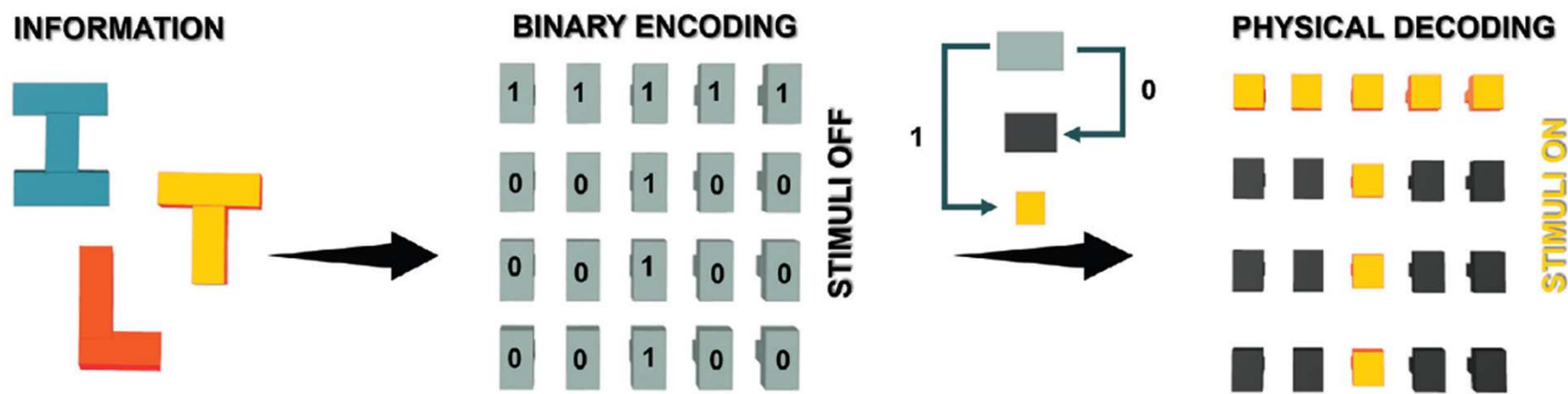


Shape-changing behavior

LIQUID CRYSTALLINE NETWORK

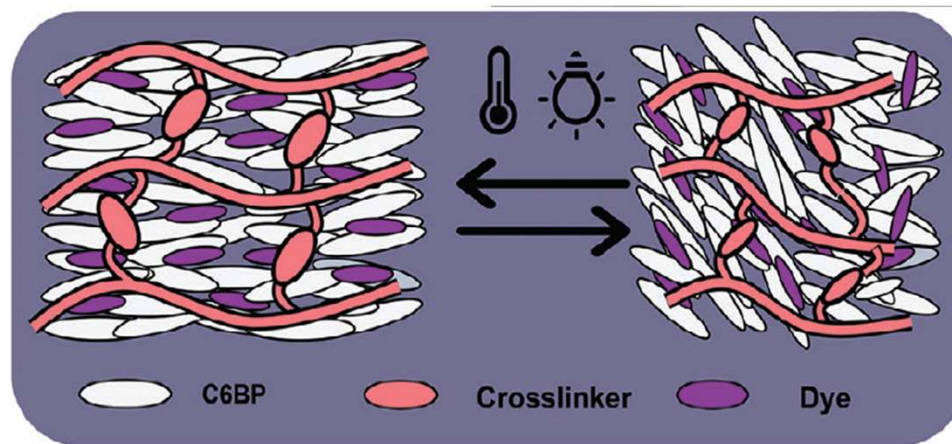
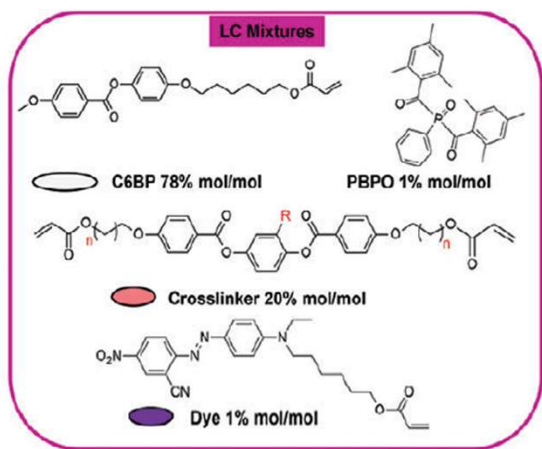


Information encoding in smart microtags

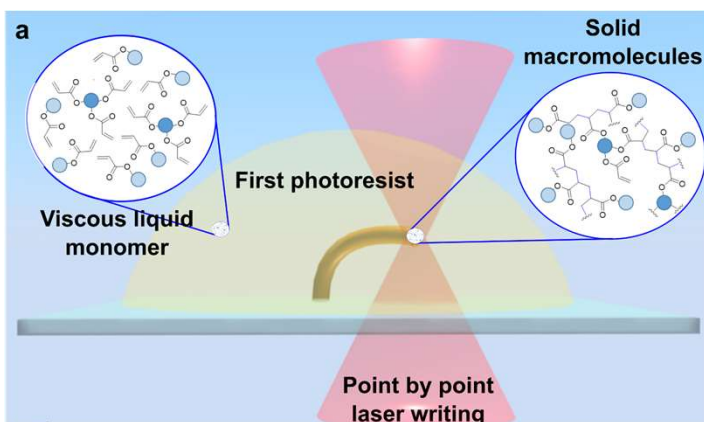


Our invisible physical ink

LCN formulation and two-photon lithography

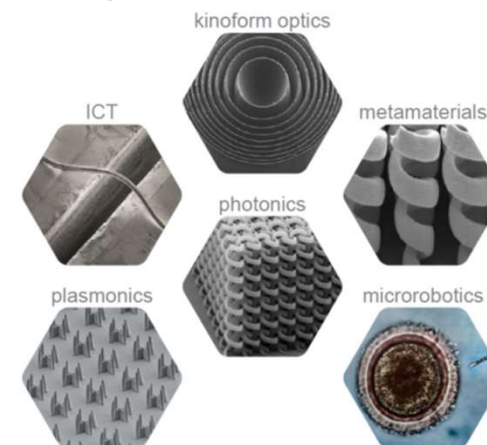
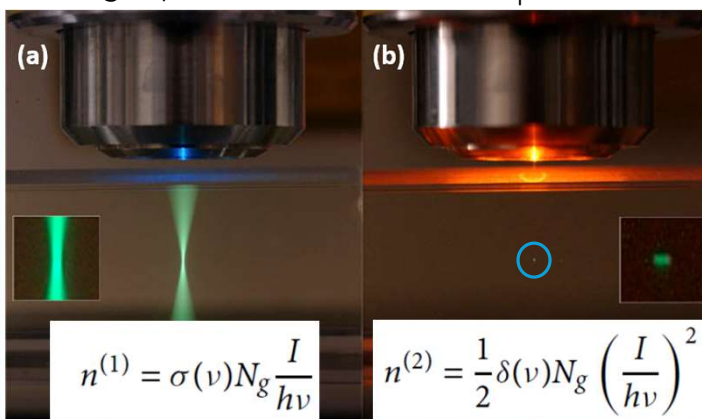


Two-photon absorption polymerization for 3D (or 4D) nano patterning



Single photon

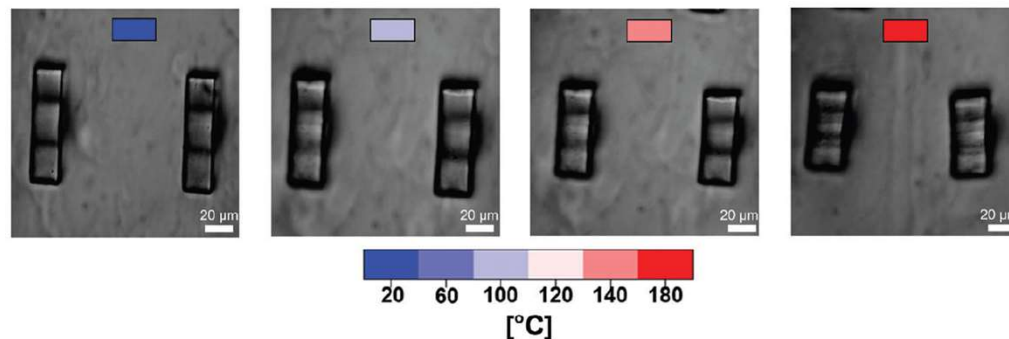
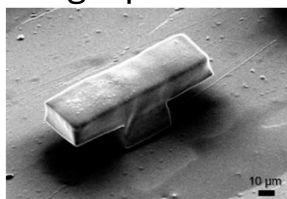
Two photons



Modulation of the shape-changing properties

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

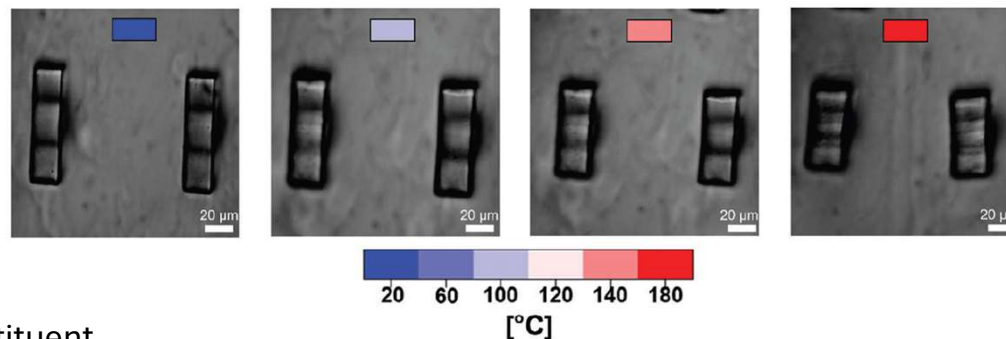
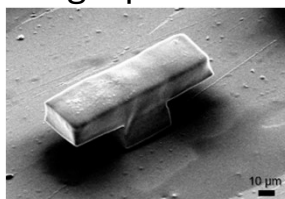
Single pixel unit



Modulation of the shape-changing properties

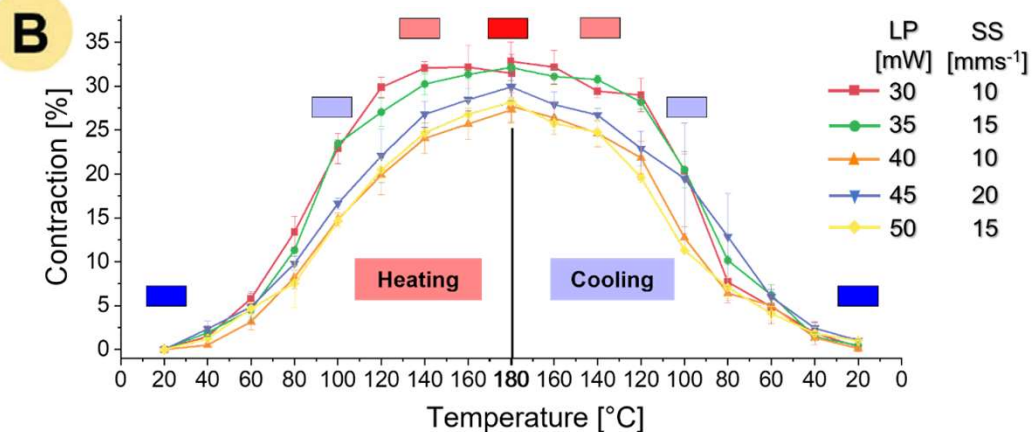
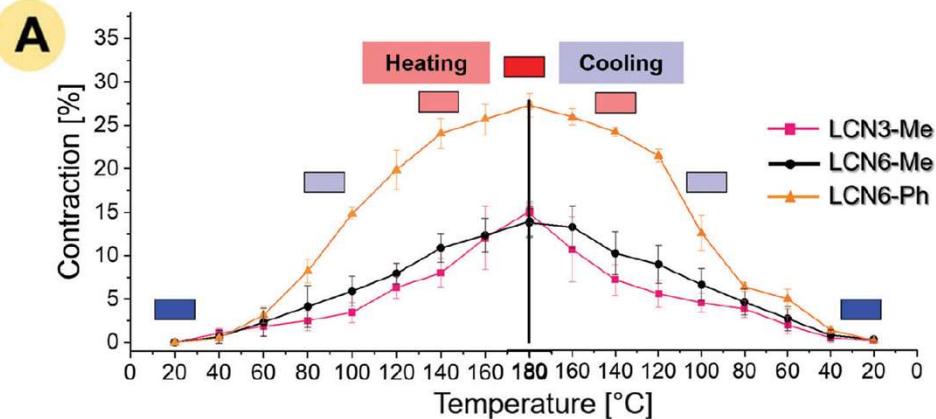
GOAL : Active elements with different deformations (under a constant stimulus) using a single LCN formulation

Single pixel unit



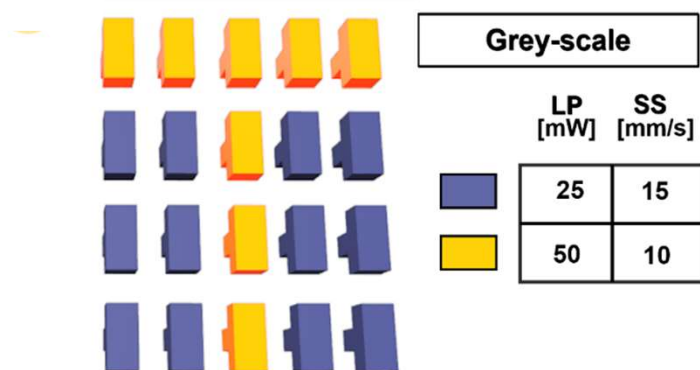
A Chemical approach : changing the LC crosslinker substituent

B Physical approach : tuning the lithographic parameters (laser power, scanning speed), “grey-scale” approach

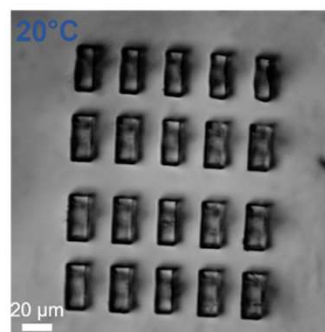


Information encoding and decoding

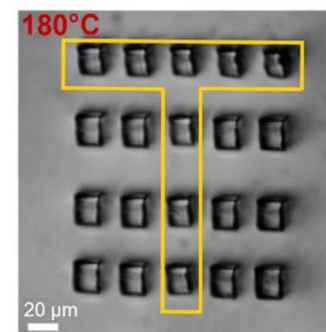
1° Level encryption/decryption



Encoded

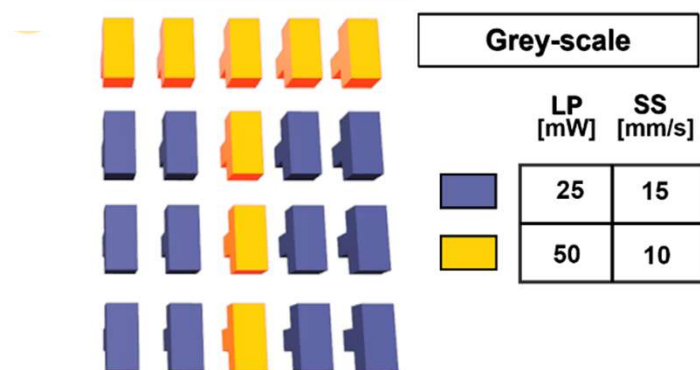


Decoded

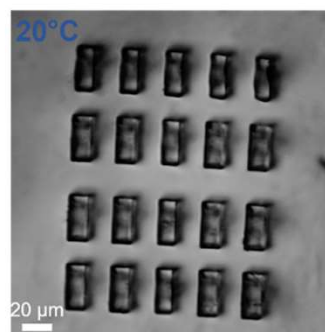


Information encoding and decoding

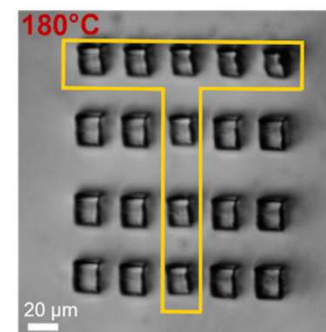
1° Level encryption/decryption



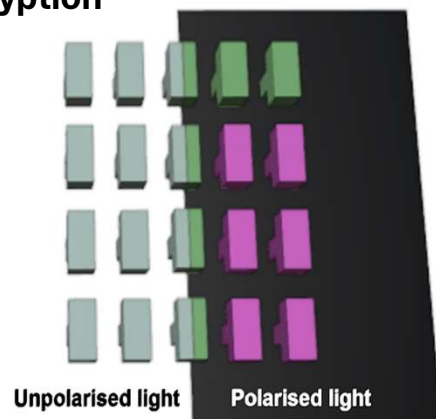
Encoded



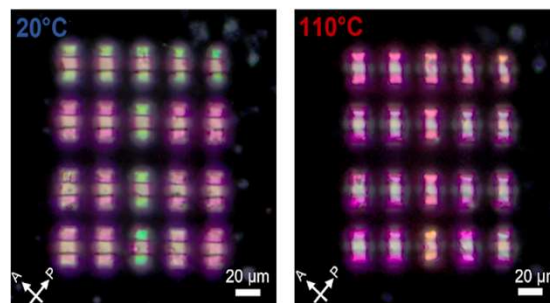
Decoded



2° Level encryption/decryption

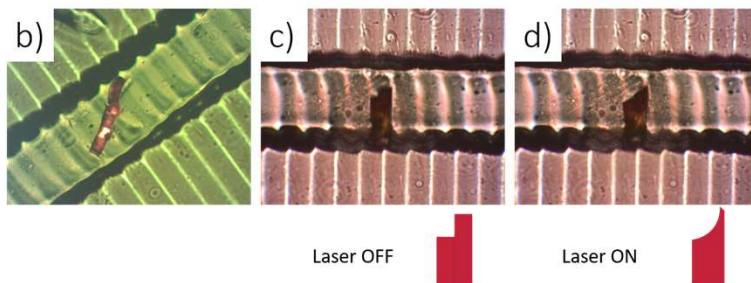
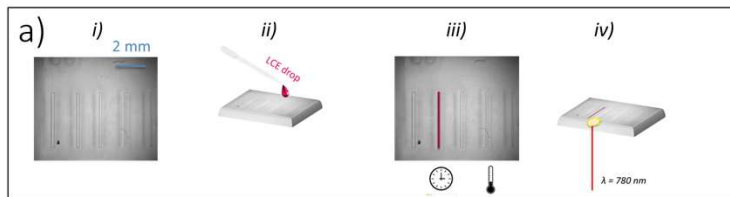


Polarized light + temperature decoding



Encode and decode information in smart tags in response to external stimuli thanks to shape-changing polymers

Twinning for excellence of the Serbian Research Center for quantum biophotonics

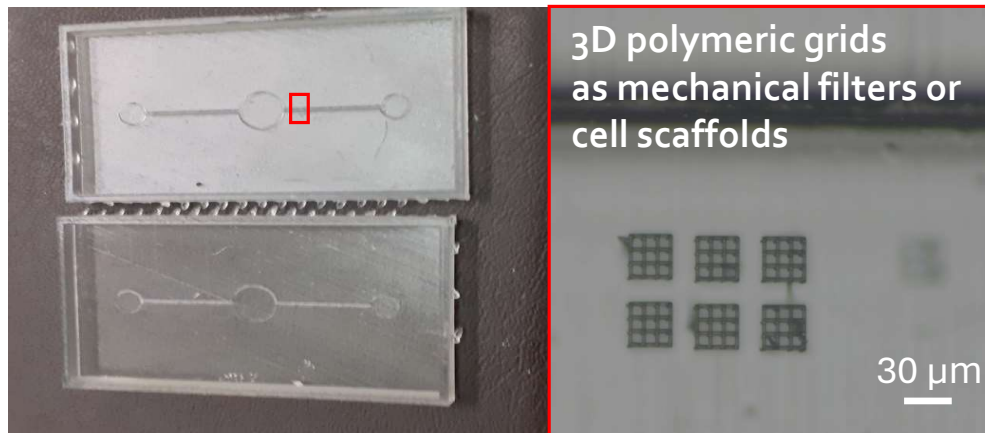


BioQuantSense



Twinning for excellence of the Serbian Research Center for quantum biophotonics

Integration of active and passive 3D microstructures in microfluidic circuits



BioQuantSense





The hidden value of responsive materials

**Sara Nocentini, S. Donato, D. Martella, C. Parmeggiani,
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