Smart Materials by Inkjet

iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland

13 September 2023 By Muriel Mauron – muriel.mauron@hefr.ch

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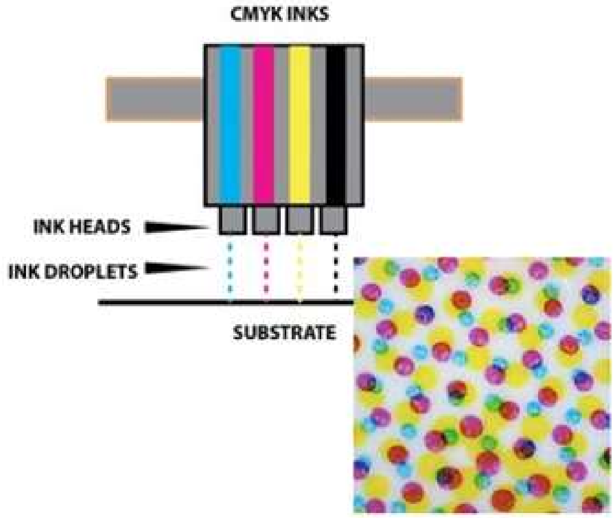
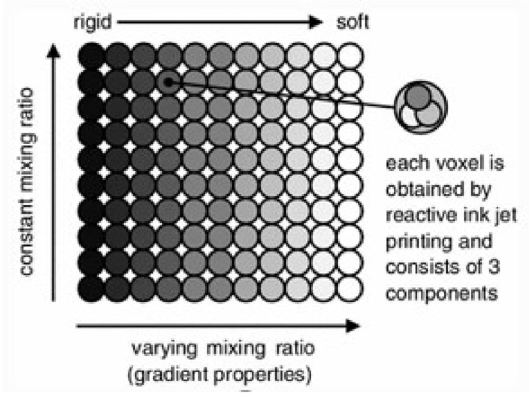
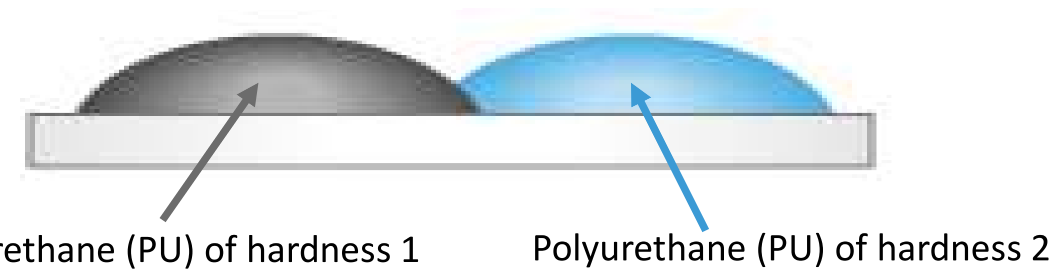
Our approach

Tailored Functional surface





Study of inkjet printing as additive manufacturing process for gradient polyurethane material, *Prod. Eng.*, vol. 8, no. 1–2, pp. 25–32, 2014



Visualization with the mechanochrome

Mechanochromic additive

tOPV additive developed by the Adolphe Merkle institute (AMI) :

- Reversible and highly sensitive
- Mechanical deformation → Fluorescence color change gradually
- Correlation between color and applied deformation

Mechanoresponsive Elastomers Made with Excimer-Forming Telechelics. Org. Mater. 2020, 02 (04), 313–322.

Images taken under UV illumination of an elastomeric polyurethane/tOPV blend film containing 0.2 wt% tOPV subjected to uniaxial tensile deformation at the indicated strains

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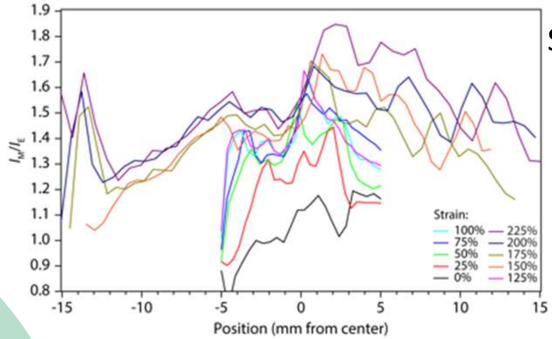
Smart material by inkjet

INK FORMULATION

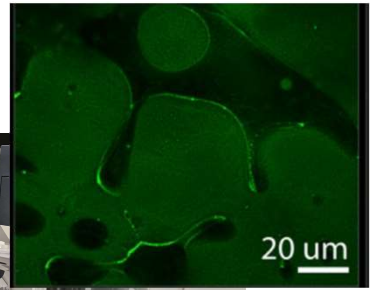
PU selection

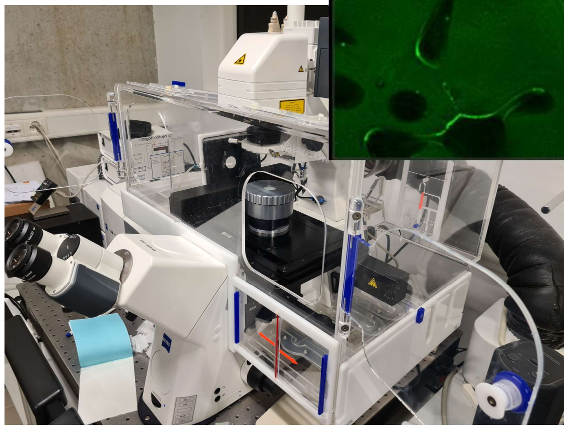
Mechanochromic additive

Solvent selection



Spectroscopic analysis (optical fiber)





Confocal microscope

Inkjet printing → Drying → Sample elongation under UV light → Monomer to excimer ratio measurement

Substrate
Printhead

Temperature and time

Spectroscopic analysis
Confocal microscope

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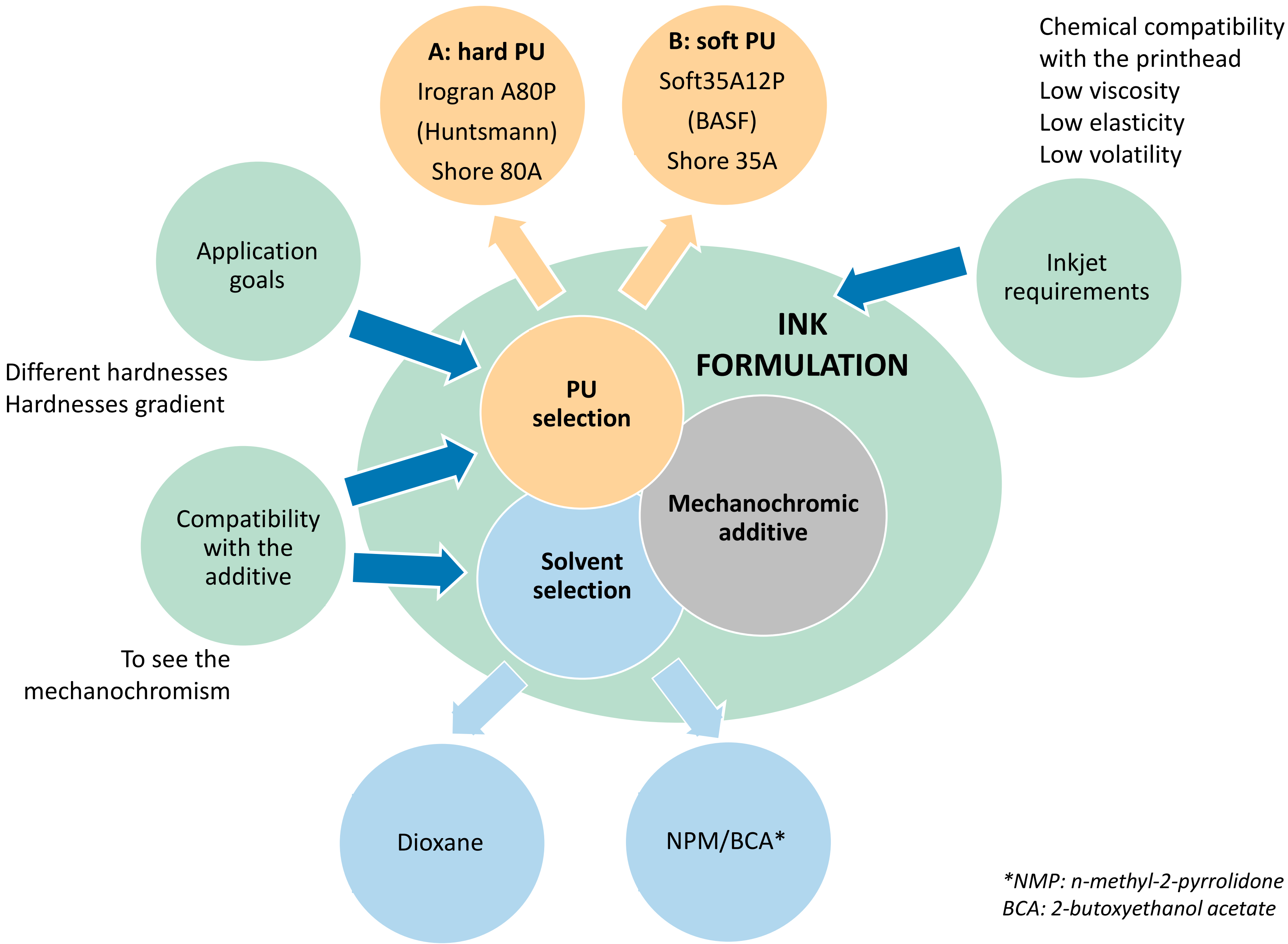
Ink formulation



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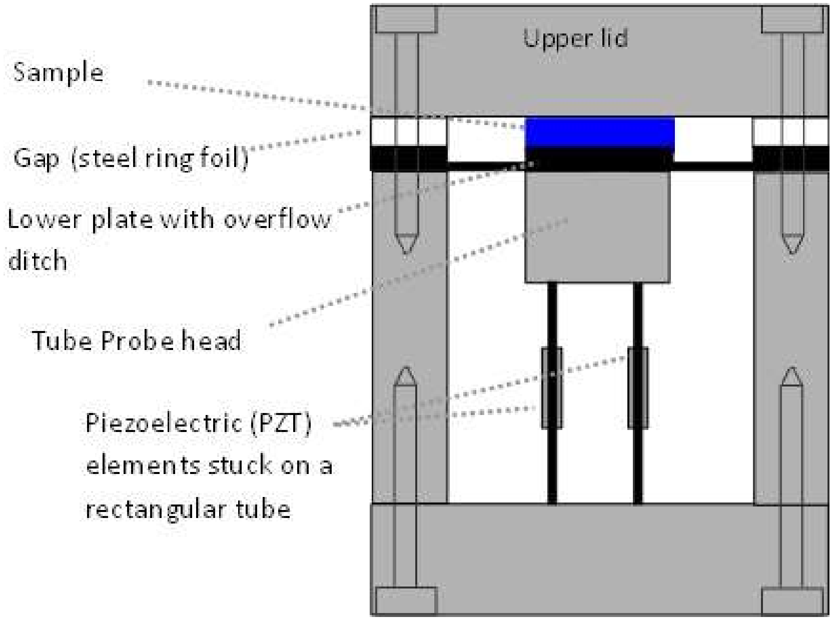
Ink formulation

- Final inks concentration determination
- Piezo Axial Vibrator (PAV) device
- Measurement of the complex viscosity at different frequencies and temperatures
- Tests with different dilutions to have inkjet properties



https://trijet.co.uk/

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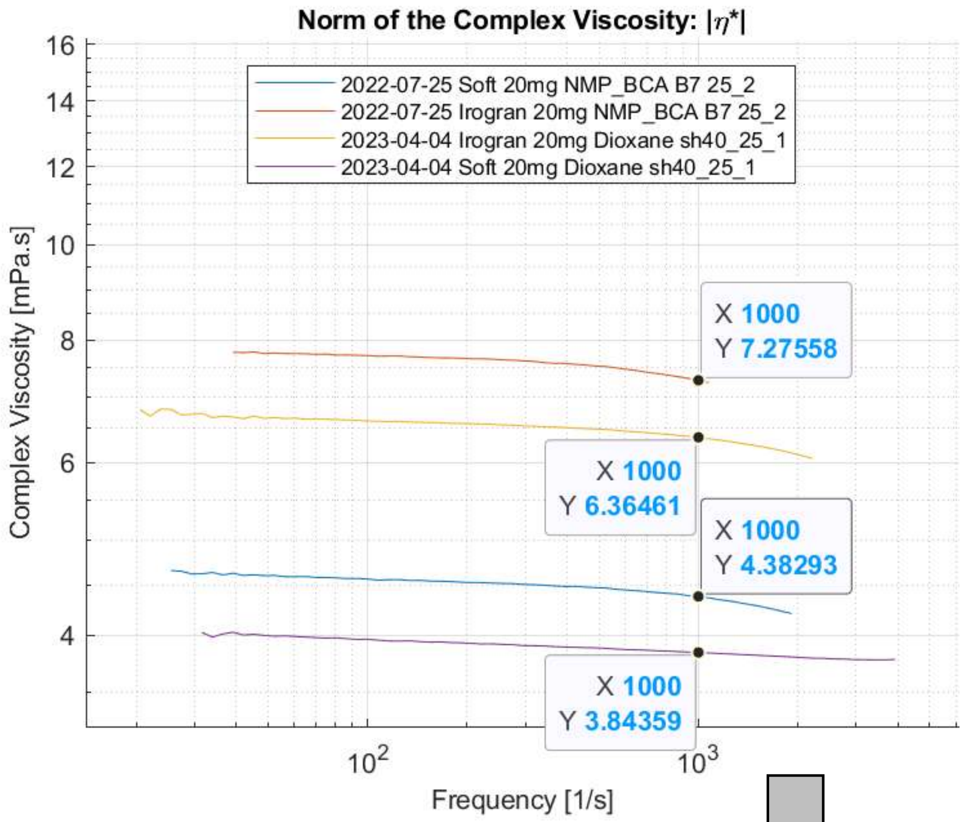
Viscosity measurements

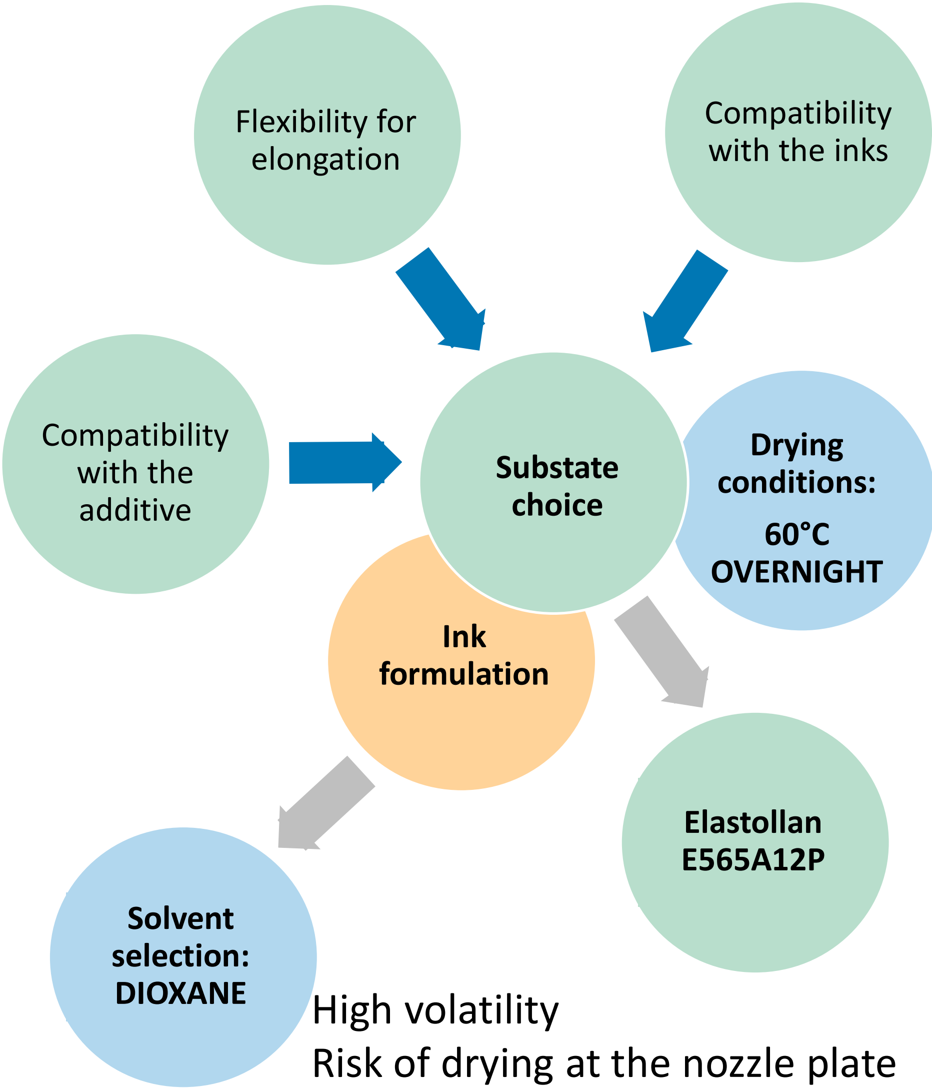


- Good viscosity for inkjet printing for the 4 selected inks
- Type of solvent doesn't affect the viscosity of the ink

INK A (hard)
20mg/ml irogranA80P in dioxane
OR
20mg/ml irogranA80P in NMP/BCA

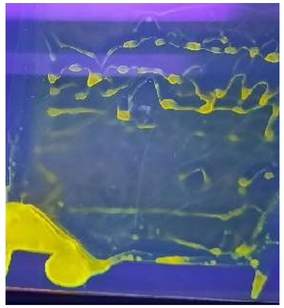
INK B (soft)
20mg/ml soft35A12P in dioxane
OR
20mg/ml soft35A12P in NMP/BCA

Solvent and substrate choice



High volatility
Risk of drying at the nozzle plate

120°C
Green: dye not fixed to polymer (bad)



60°C
Yellow-brown: dye fixed to polymer (good)

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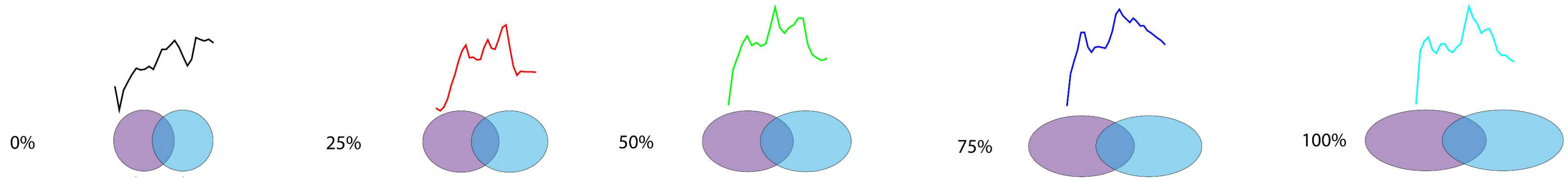
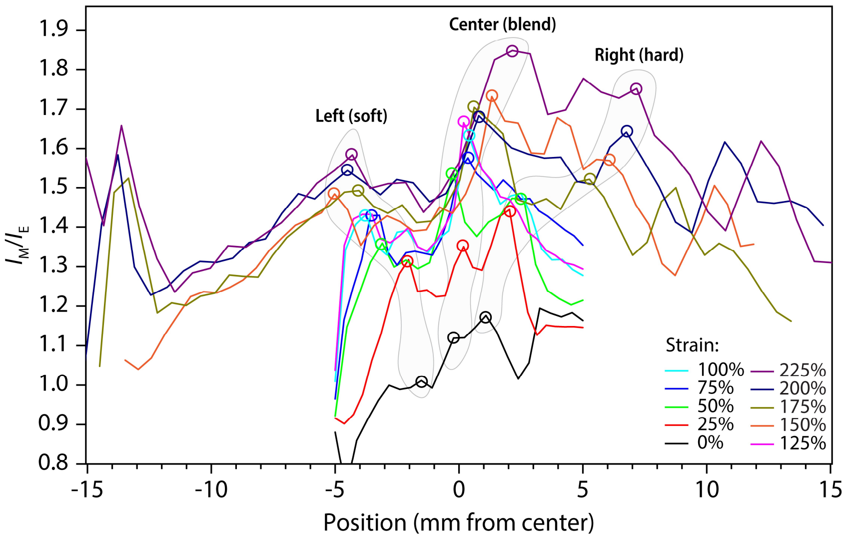
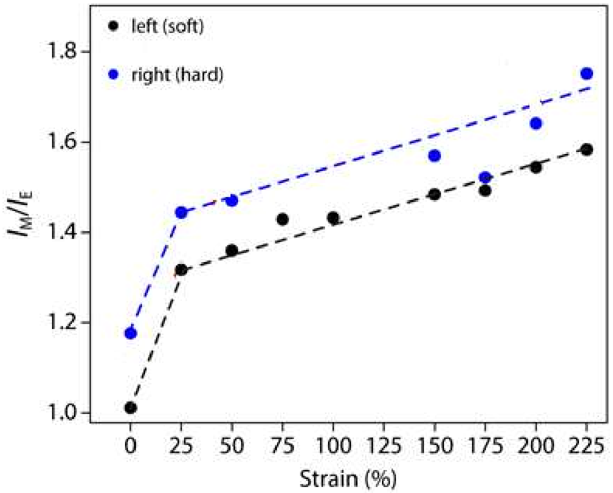
Dropcast samples







- Harder PU exhibit higher I_M/I_E values than softer PU
- Intensity increase with strain

mechanochromism of the different dropcasted PU inks

PU/tOPV 1wt% in dioxane
Substrate: elastollan 565A12P

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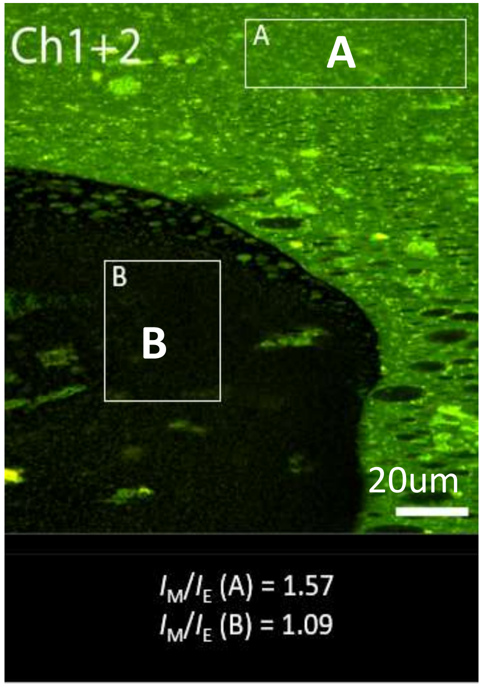
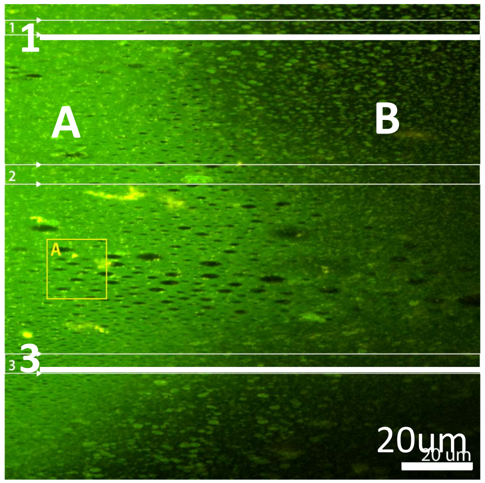
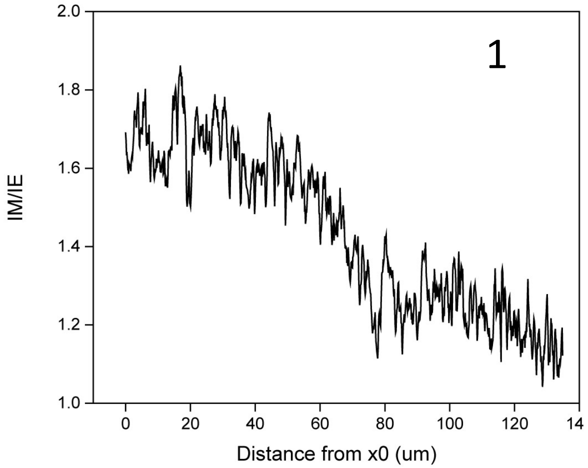
Dropcast samples

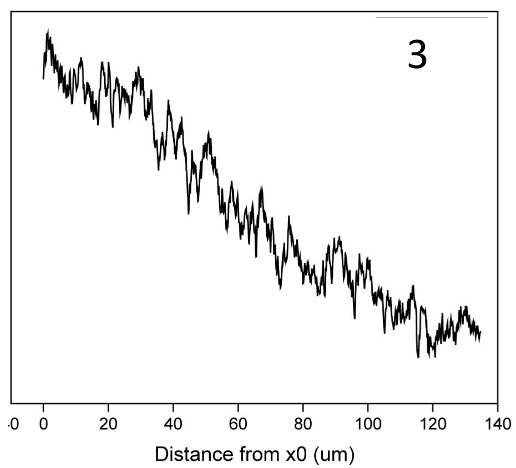


PU/tOPV 1wt% in doxane
Substrate: elastollan 565A12P
90% strain

INK A: hard PU
INK B: soft PU







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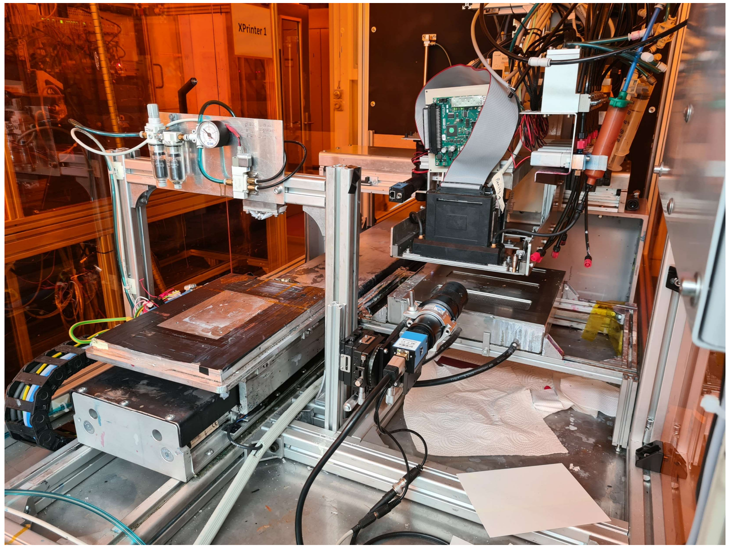
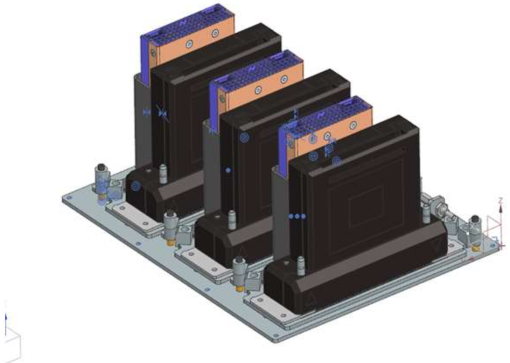
Inkjet printer

Seiko RC1536 printhead



Inkjet printing platform



Printheads mounted in parallel for multi-material jetting

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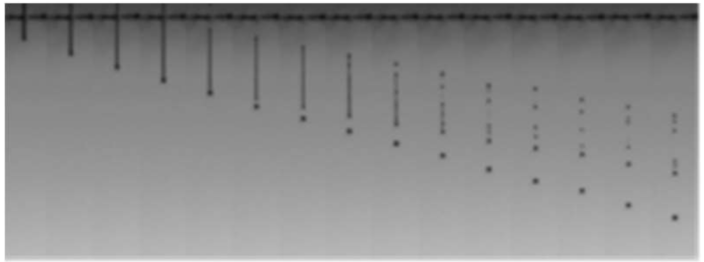
Dropwatching



Example of jetting with non-optimised waveform

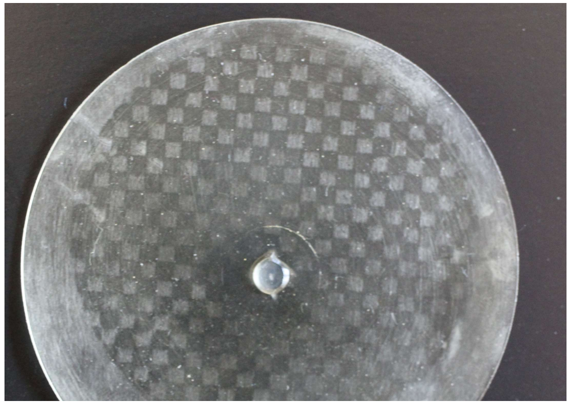
Example of jetting with optimised waveform

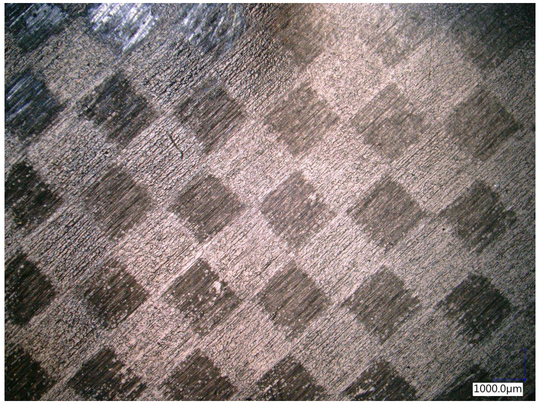
- Difficulties due to quick drying at the nozzle plate
- Applied voltage drastically increased to allow recovery of the quicky-drying nozzles
- Larger drops with satellites
- Printing quality issues
- Decrease the concentration of ink A

INK A (hard)
15mg/ml irogranA80P in dioxane

INK B (soft)
20mg/ml soft35A12P in dioxane

Printing patterns





Chessboard pattern (square side: 1mm)

- Singer layer and multilayer (up to 20 layers)
- Ink A and ink B simultaneously printed
- Different pattern tested: chessboard, lines and concentric lines

Concentric lines pattern

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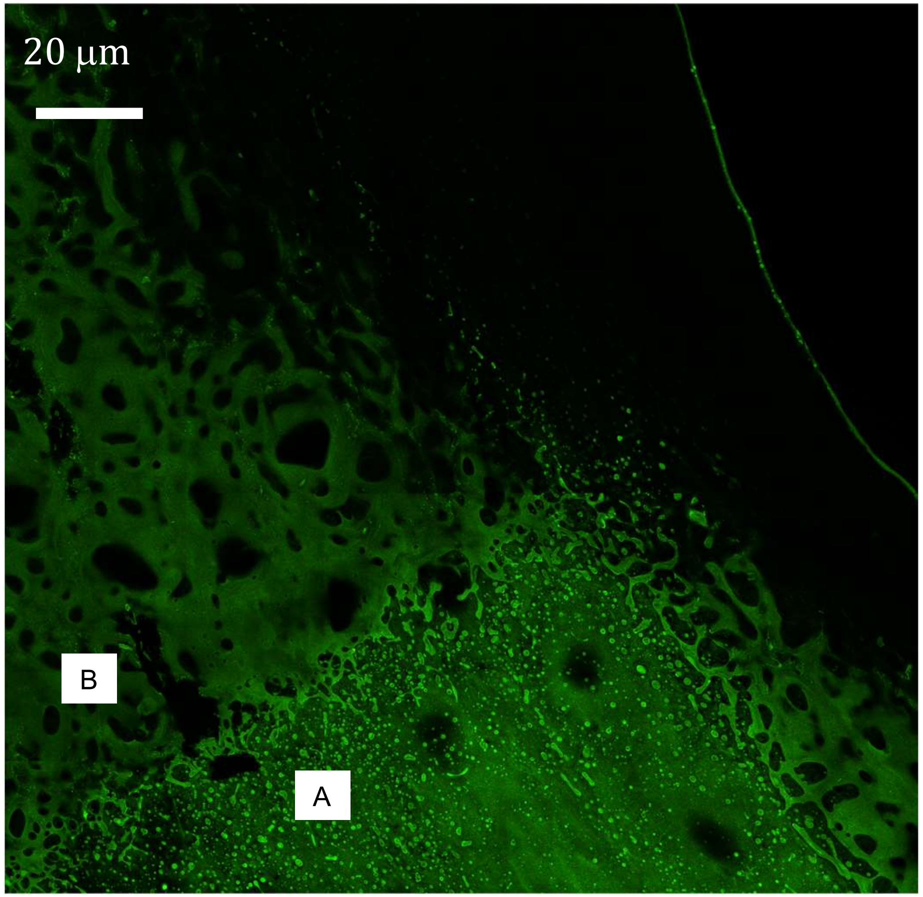
Printed samples analysis



- Confocal microscope image of an inkjet printed sample (chessboard pattern)
- Ink A: harder PU
- Ink B: softer PU
- Visible interface between the two inks

- Printing quality issues
- Lots of satellites (high voltage because too fast drying in the nozzles)
- Black spots: dewetting

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Conclusions

- Mechanochromism demonstrated in dropcast samples of two smart inks
- Unexpected factors discovered
  - Influence of drying and evaporation speed of the solvent on the mechanocromism
  - Influence of the substrate on the mechanochromism
- Challenges faced during the printing process due to the drying at the nozzles
- First step to build up basic understanding on multimaterial droplet interaction

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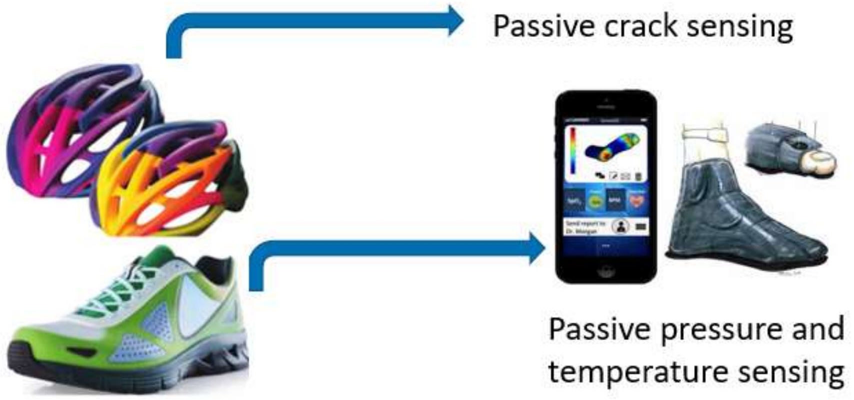
Next step and applications

- Next steps:
  - Inkjet printing with higher homogeneity
  - Characterization of the gardient material using mechanochromism
  - Numerical simulation to predict the mechanical properties of the mixing drops

Future applications:

- Create materials with gradient properties at high resolution
- Create unique properties by material combination
- Passive crack sensing
- Passive pressure and temperature sensing



Team and support

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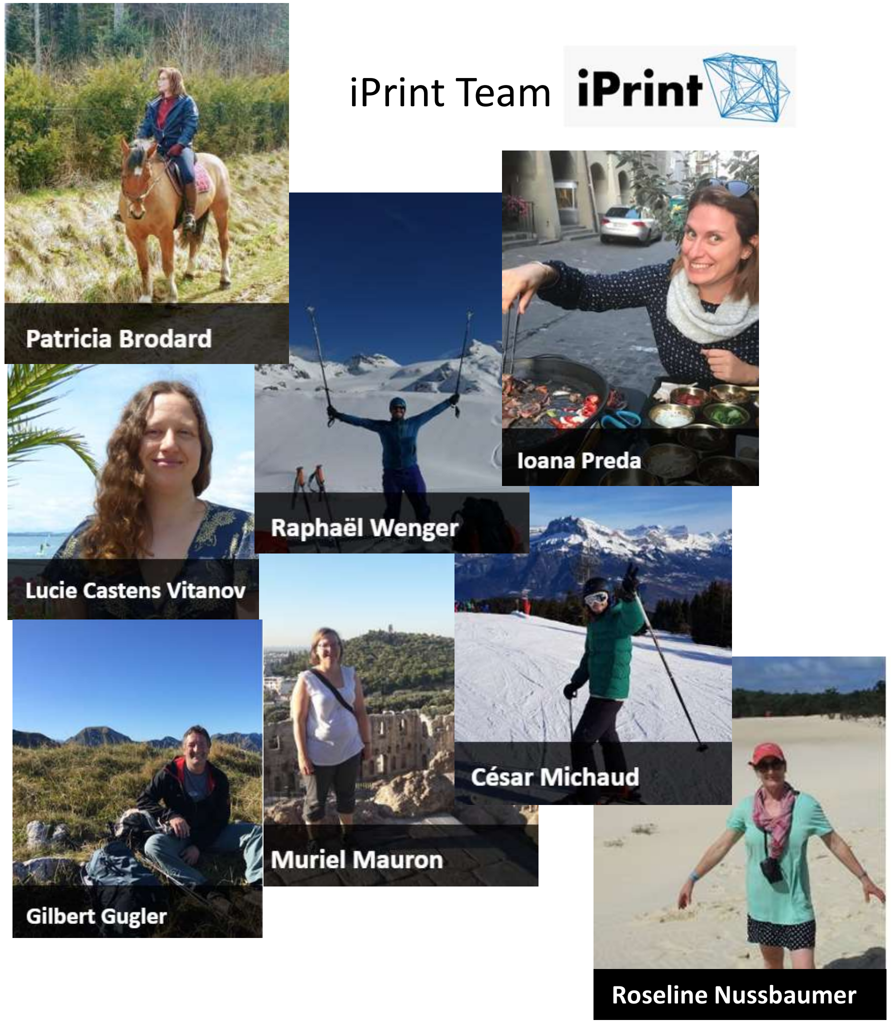
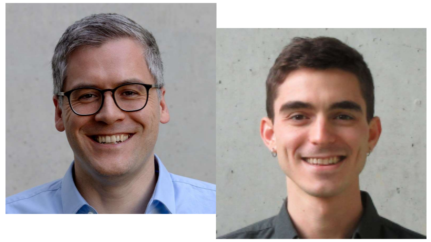


This project was funded by HES-SO University of Applied Sciences and Arts Western Switzerland, Engineering & Architecture

Adolph Merkle Institut



Stephen Schrettl & Derek Kiebala
Polymer Chemestry & Materials

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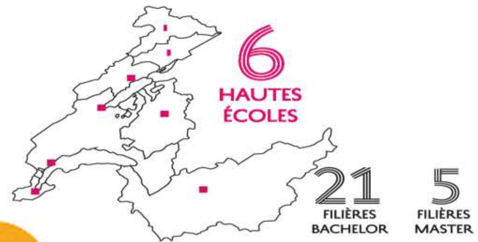

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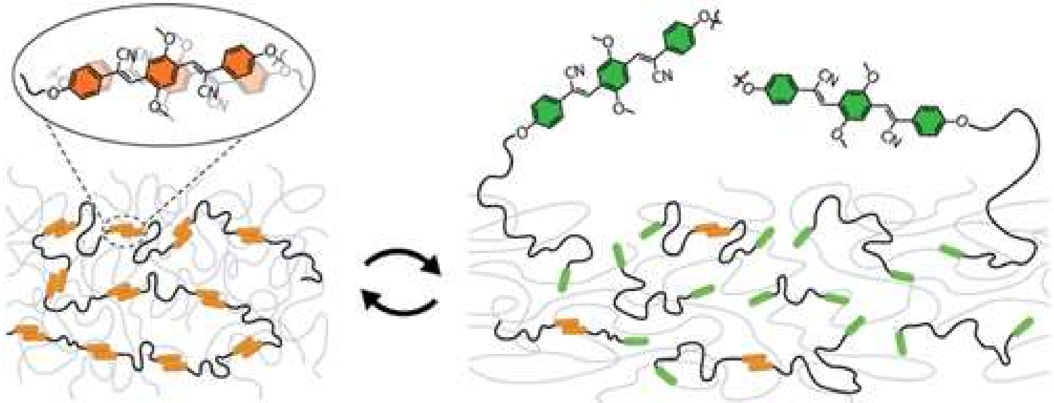
Mechanochromic additive

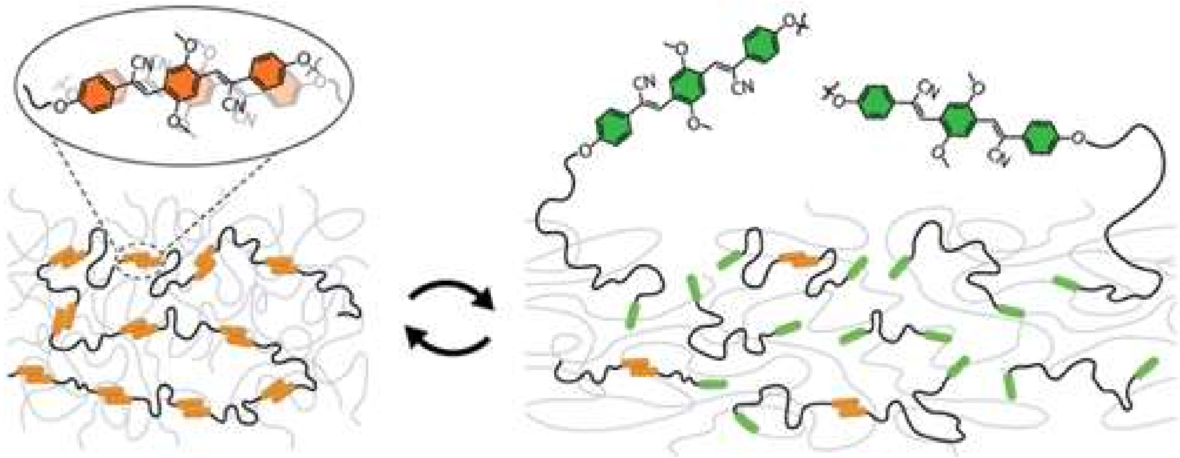
- Mechanoresponsive polymer material by the incorporation of a mechanoresponsive luminescent material (MRL)
- Change of the fluorescence colour in response to mechanical deformation
- Excimer-forming dye: formation of phase-separated aggregates when blended with a polymer
- Mechanical deformation of the blend film can disrupt the aggregates and release individual dye molecules
- The dye emits at different wavelengths in its aggregates and monomeric states, with fluorescence colour change in the deformed material

Mechanoresponsive Elastomers Made with Excimer-Forming Telechelics. Org. Mater. 2020, 02 (04), 313–322



Mechanochromic additive

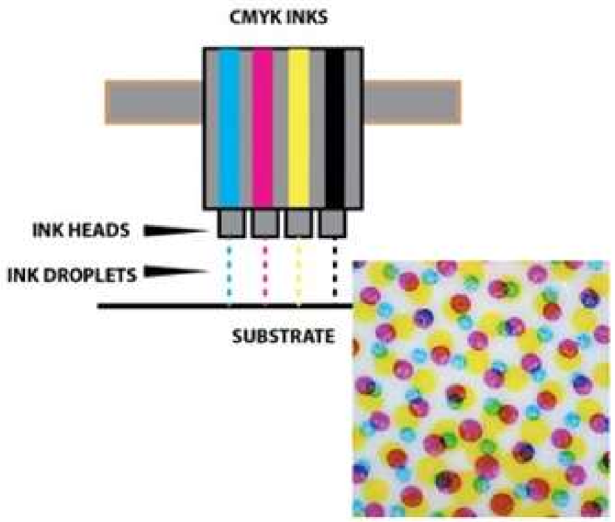
- Mechanoresponsive luminescent material (MRL)
- Mechanical deformation → change of the fluorescence colour
- Excimer-forming dye blended with a polymer → phase-separated aggregates
- Mechanical deformation of the blend film → release of individual dye molecules
- Aggregates and monomers emit at different wavelengths → fluorescence colour change in the deformed material



Mechanoresponsive Elastomers Made with Excimer-Forming Telechelics. Org. Mater. 2020, 02 (04), 313–322

Inspiration

Inkjet printing



3D Printed Multimaterial

https://www.x-mol.com/paper/5949518

Resolution: 10-100μm 100-1000μm

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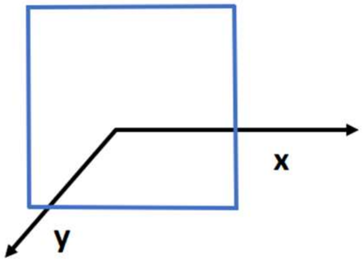
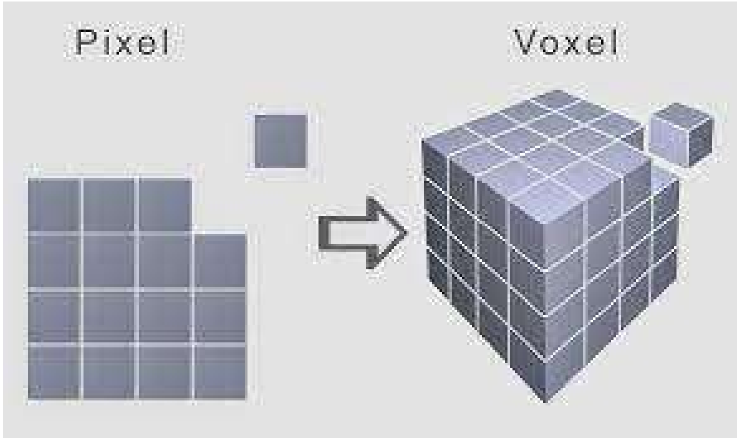
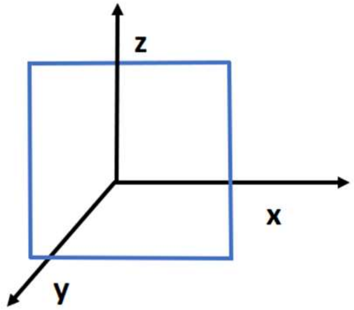
Inspiration







https://www.nicepng.com/ourpic/u2e6a9u2e6a9t4o0_a-voxel-is-the-3d-equivalent-of-a/

Drop on demand inkjet printing → single layer

+

Z axis → Layer by layer construction of 3D structure

+

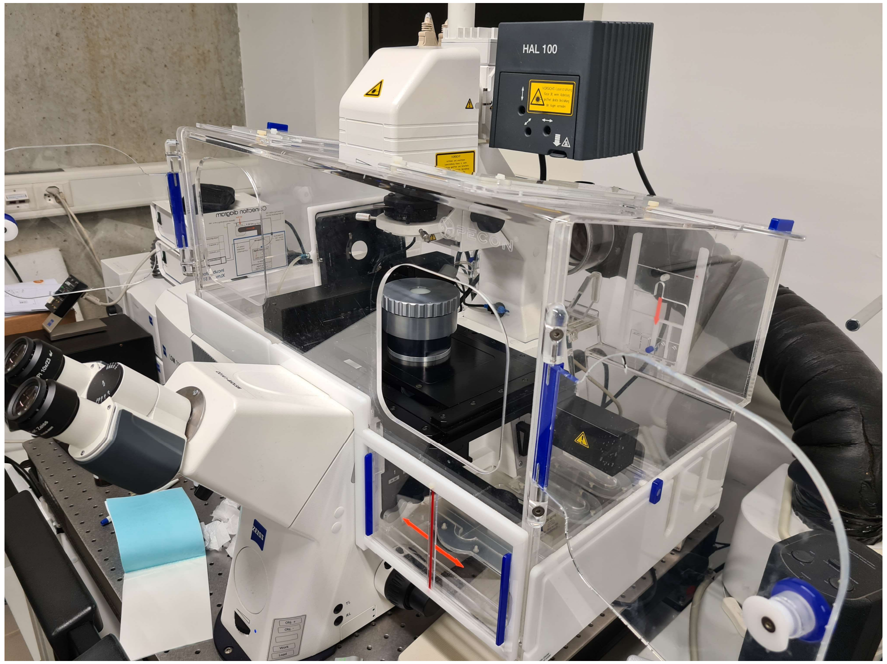
Functional inks with different properties

↓

Smart materials by inkjet

Printed samples analysis

- Measurement of the local monomer-to-excimer ratio during the elongation of the sample
- Special tool developed by the AMI to elongate the samples uniformly (round samples)
- With confocal microscope to increase the resolution during visualisation (compared to the spectroscopic analysis done on the dropcast samples)



Confocal microscope with the special tool to elongate the samples

Dropcast samples

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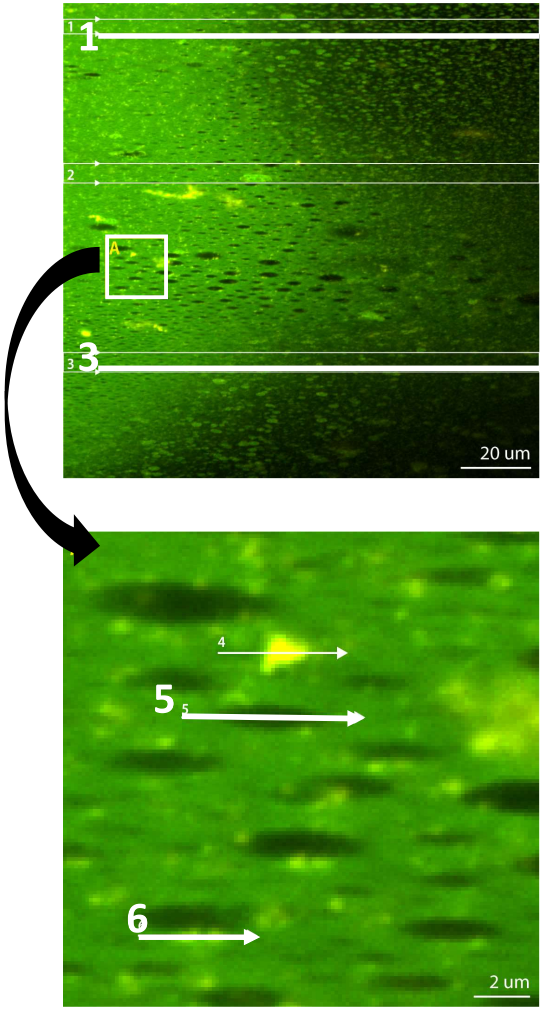

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Substrate: elastollan 565A12P