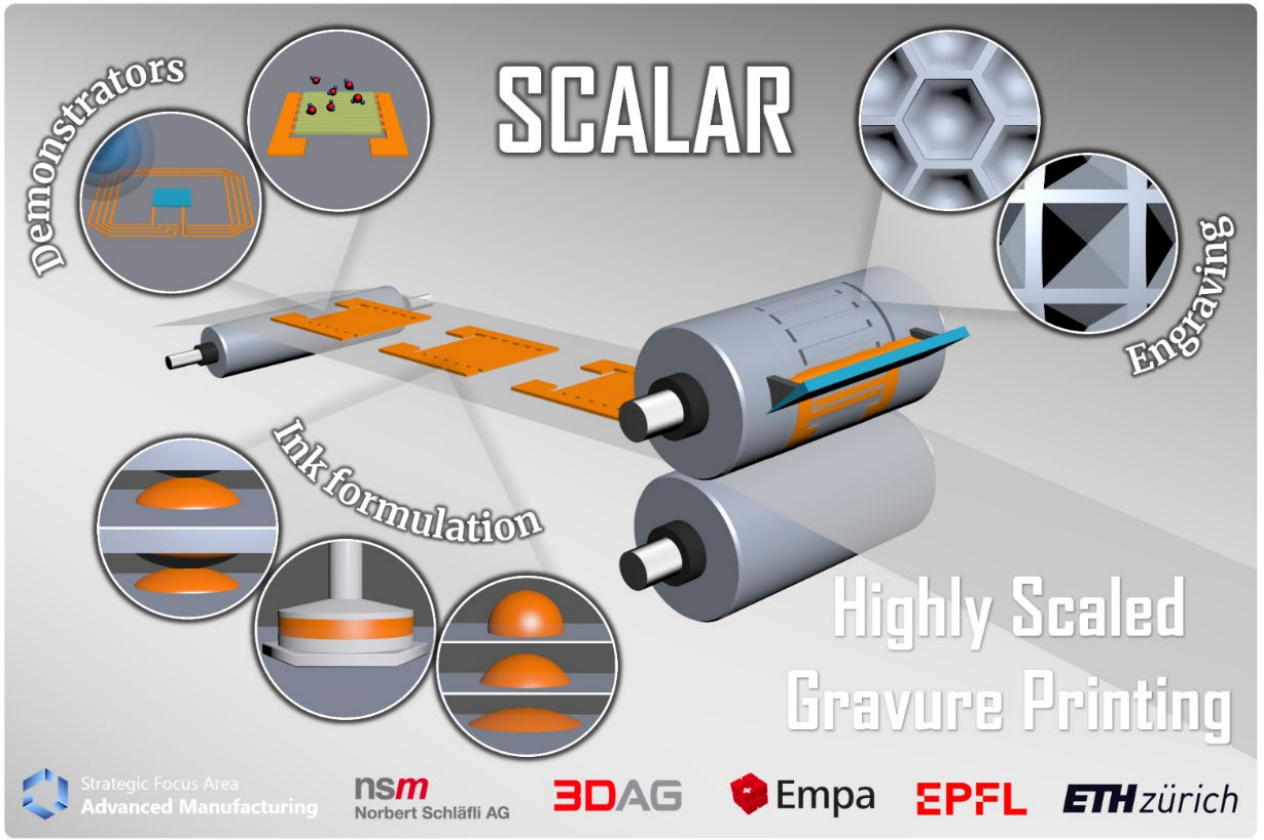
Strategic Focus Area
Advanced Manufacturing

Highly Scaled Gravure Printing

SFA-AM Review Meeting
PSI, 8 February 2023
Jakob Heier & SCALAR team

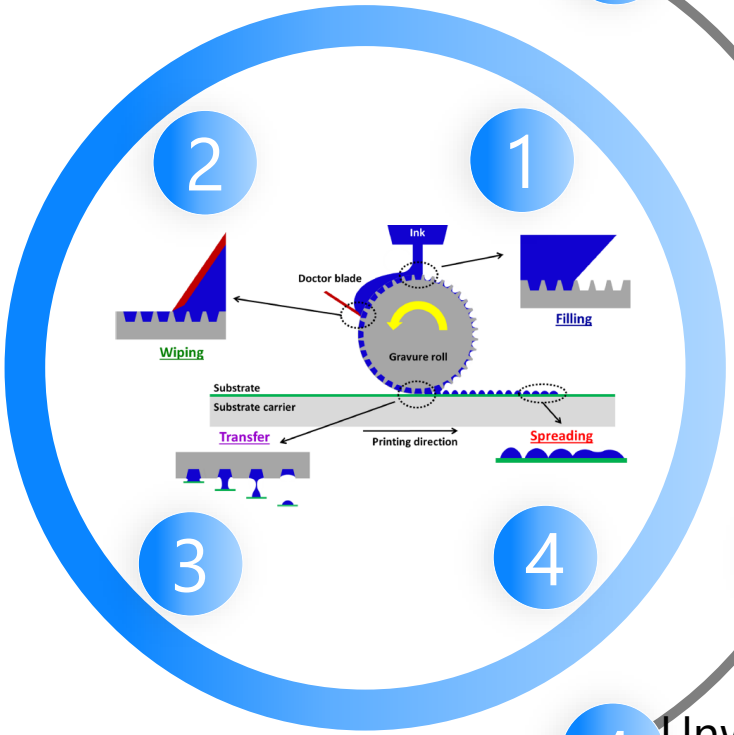


SCALAR: Objectives

- The objective of this project is to **establish gravure printing as manufacturing technology** for applications in printed electronics and opto-electronics.
- We define highly scaled gravure printing as "printing **2 µm wide conductive line-features** at a speed of **1 m/s** on a DIN A5 area".

- **SCALAR will make it possible to introduce electronic functionality in large quantities at low cost to products, e.g. printed sensors in a pandemic situation**

- vs State of the Art Graphic Arts Industry:
  - Higher resolution
  - Functional inks
  - Lower speed



1 Air entrapement

Shape of cavity
Capillary number

2 Lubrication film
Drag out

Shape of cavity
Capillary number
Blade:
material/angle/pressure

3 Poor transfer

Shape of cavity
Capillary number
Cylinder pressure

4 Unwanted pattern

Capillary number
Substrate

Problem: optimum different for each of the individual subprocesses

Which subprocess is limiting?

Compromise?

01

Shape of cavity:

We develop a fully new process to fabricate a structured gravure cylinder

02

Capillary number:

Synthesis and formulation of novel gravure printing inks, theory of the process

03

Printer hard- and software

Position and force controlled nip pressure between printing cylinder and substrate and between doctor blade and printing cylinder; variable doctor blade angle 55° - 65°.

04

Demonstrators

Consortium


V. Subramanian

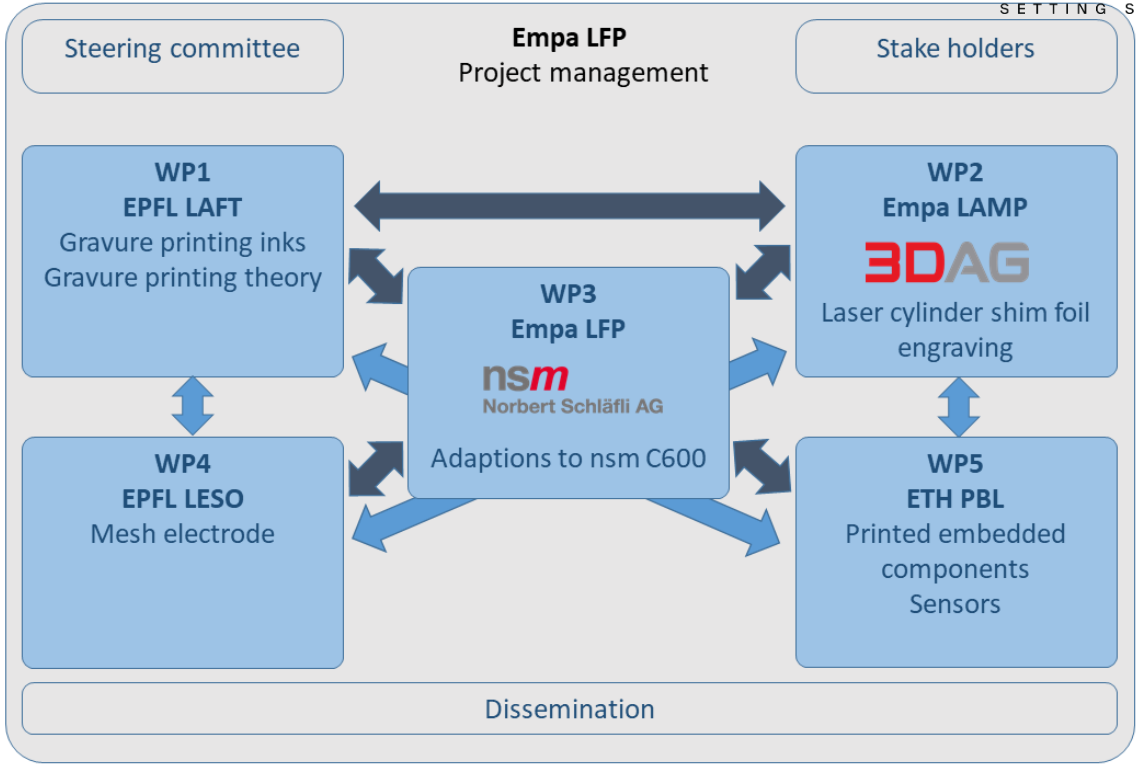


A. Schüler J. Fleury



M. Jafarpour J. Heier


M. Schläfli



BOEGLIGRAVURES
SETTING STANDARDS


E. Perivolari


P. Hoffmann


M. Müller


M. Krehel


K. Dheman


M. Magno


C. Vogt

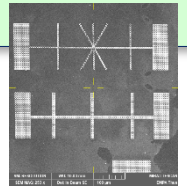
WP2 Cylinder patterning

KrF Excimer laser at 248 nm; 2 µm resolution greyscale

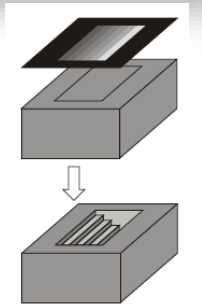
Mask fabrication external

Excellent pattern replication

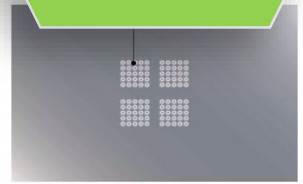
Pattern design
EPFL



Laserablation
Empa Thun



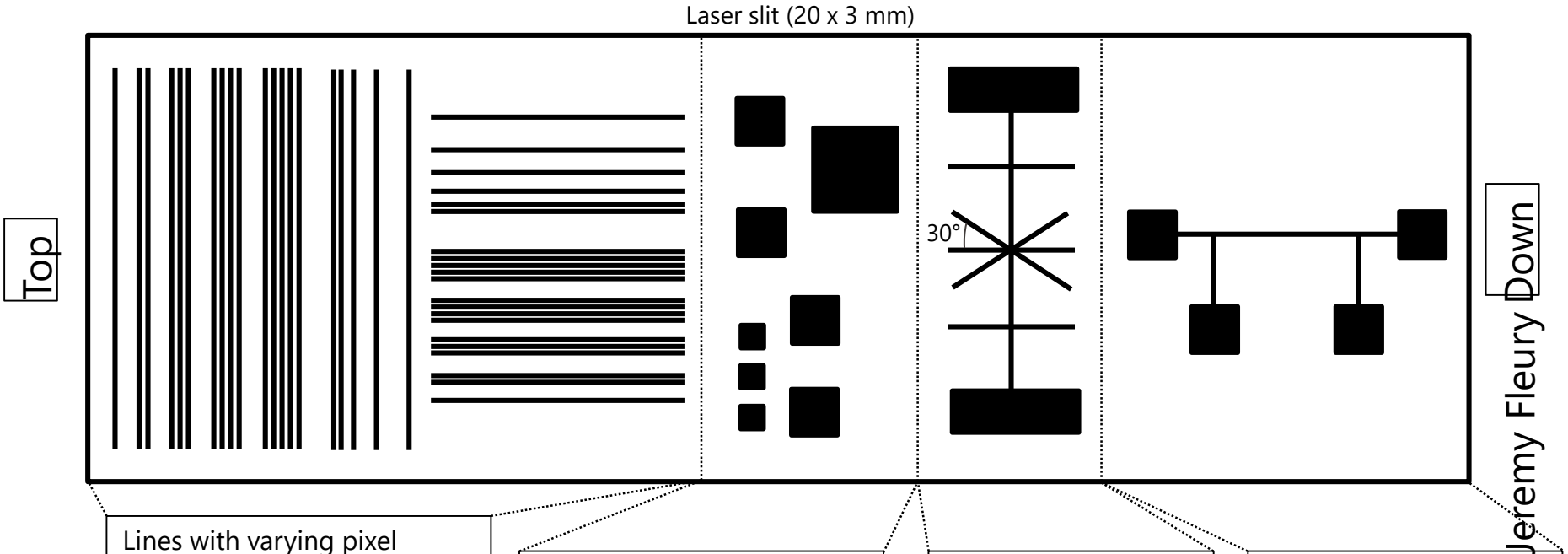
Electroforming
3DAG



Welding/ Lamination
nsm Norbert Schläfli AG
3DAG

Printing & Evaluation
Empa Dü

Design test structures (Simplified version)



Lines with varying pixel width: 1, 2, 3, 4, 5
Increasing spacing between lines:
x/2, x, 3x/2, 2x, 5x/2, 3x

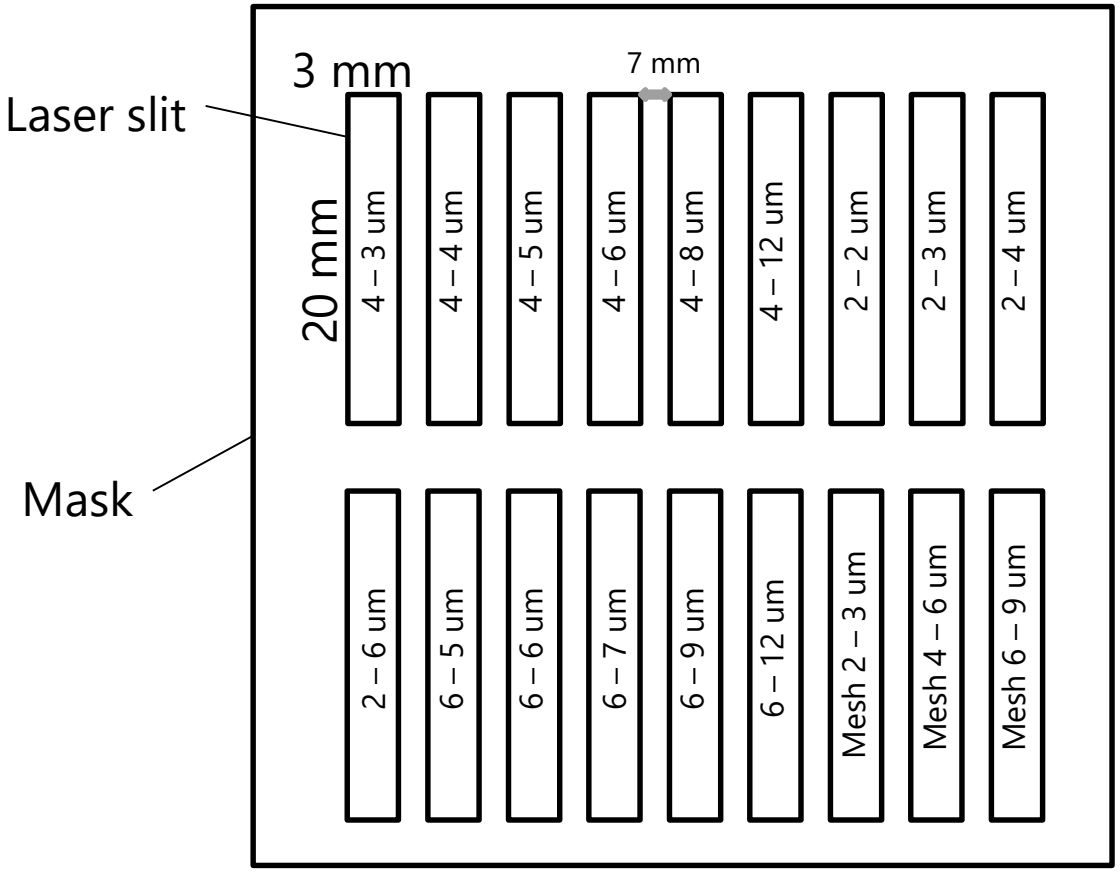
Squares with varying sizes:
2x2, 3x3, 4x4, 5x5, 10x10 pixels

Crosses and line/patch junction
(1, 2 pixels thick lines)

Electrical resistance:
4-point probes method
(1, 2, 3 pixels thick lines)

N.B.: structure o

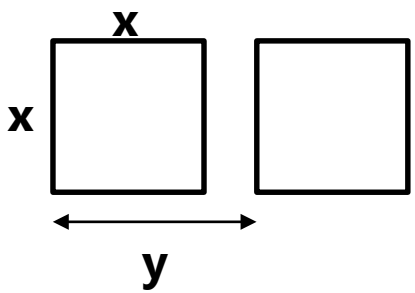
Design Mask



Nomenclature

x – **y** um

Where **x** is the pixel size and **y** is pitch



N.B.: x - y um are the final sizes of the gravure on the substrate. (they are drawn 5x larger on the GDS mask)

1st Iteration: from **shim design** to **printed features**: a steep learning curve

Shim design (EPFL/Empa)

Achievements
- Meaningful test design

Challenges
- Huge parameter space

Next steps
- Refine features
- Statistical design of experiments

Mask fabrication External

Achievements
- Design test structures to obtain optimum printing patterns

Challenges
- Resolution limit 4µm (width)

Next steps
- Grey-scale features

Laser ablation Empa Thun

Achievements
- Fine-tuning of process parameters

Challenges
- Huge amount of data / Artefacts in imaging

Next steps
- Decrease fluence to get rid of Artefacts

Ni-forming 3D AG

Achievements
- Pattern transfer as expected

Challenges
- Contaminations

Next steps

Lamination Nsm Norbert Schläfli

Achievements
- Shim on plate

Challenges
- Uniformity

Next steps
- Shim on cylinder

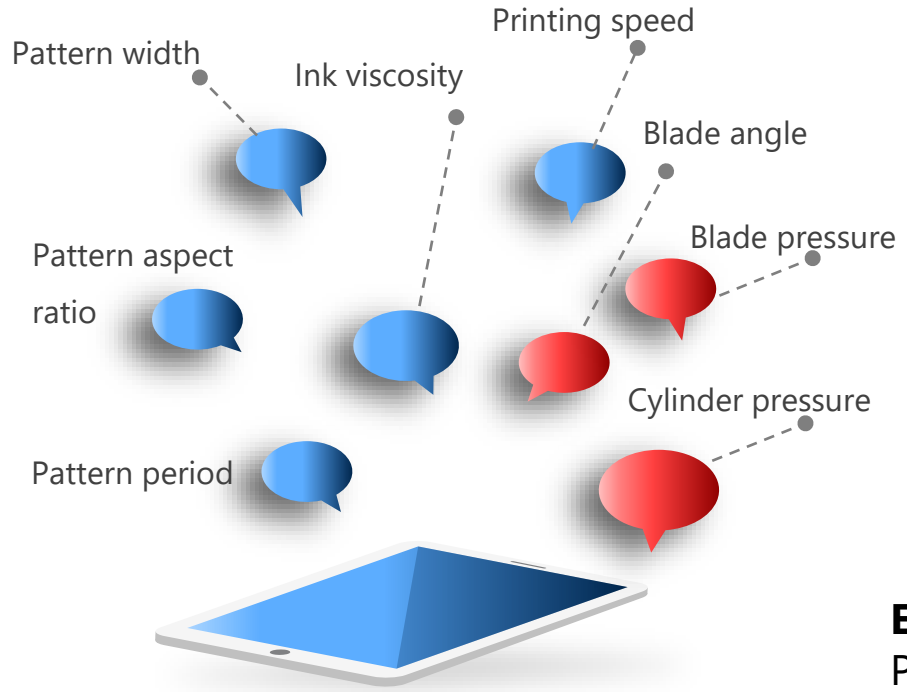
Printing test Empa Dübendorf

Achievements
- Model ink
- First insights in relevant parameters

Challenges
- Huge amount of data / Artefacts in imaging

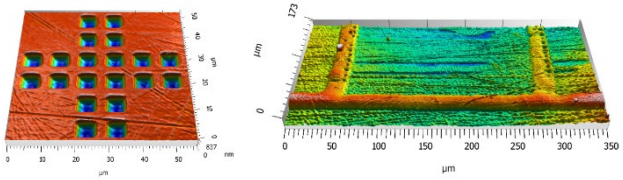
Next steps
- Functional inks

2nd Iteration

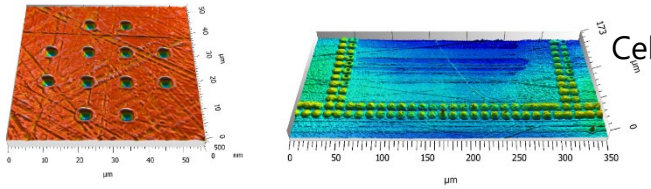


Characterization

Shim foil Transferred pattern



Cell width: 6 µm
Gap: 3 µm



Cell width: 4 µm
Gap: 8 µm

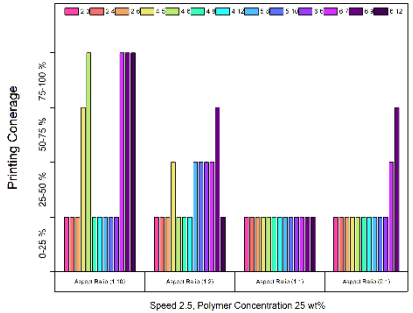
Limiting: wiping

Example analysis

Pattern fidelity

1 speed, 1 concentration

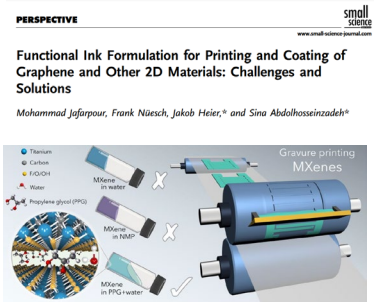
Pattern & aspect ratio varied



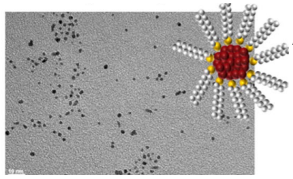
WP1 Theory & ink synthesis

Succesful synthesis of nanoparticles and ink formulations thereof

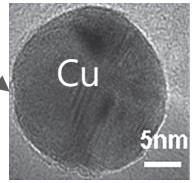
2D materials



Pt NPs



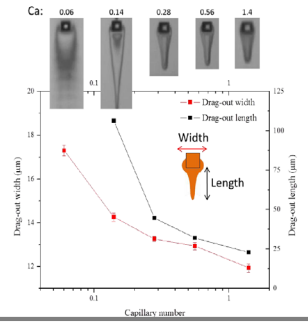
Ag/Cu core shell



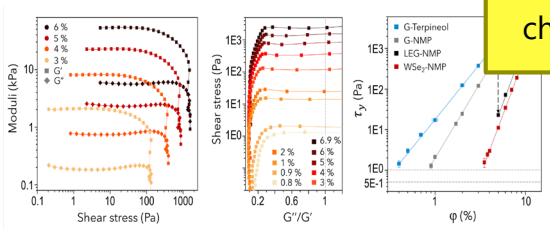
Nanoparticle & 2D materials inks

Print theory

Analysis of printed features



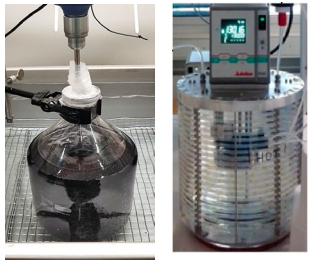
Ink characterization



Viscosity, elastic and loss modulus

Synthesis up-scaling

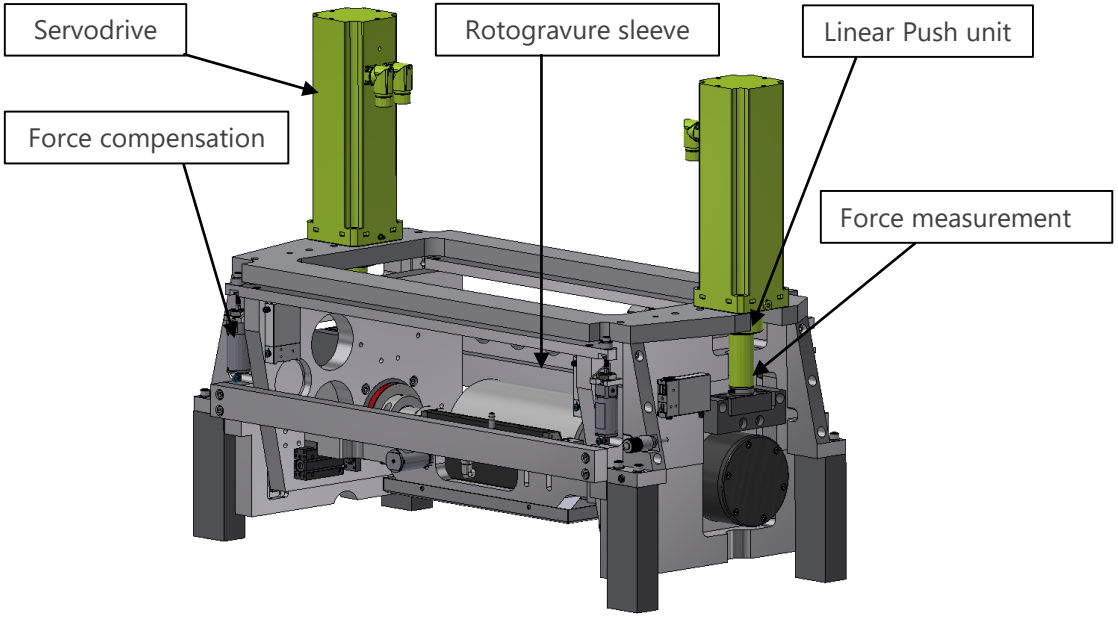
High shear mixing

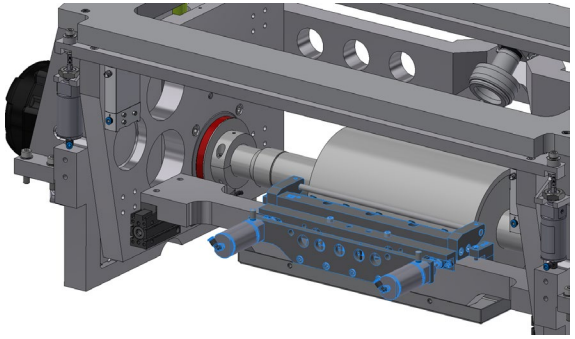


Flow reactor

WP3 - Fine tune hardware and improve software of the existing gravure printing unit of the C600 Concept Printer at CCC Empa

- Position and force controlled nip pressure between printing cylinder and substrate and between doctor blade and printing cylinder.
- Variable doctor blade angle 55° - 65°.





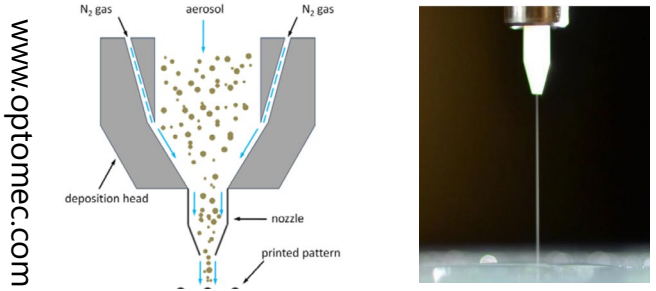
WP 4 & 5 Applications

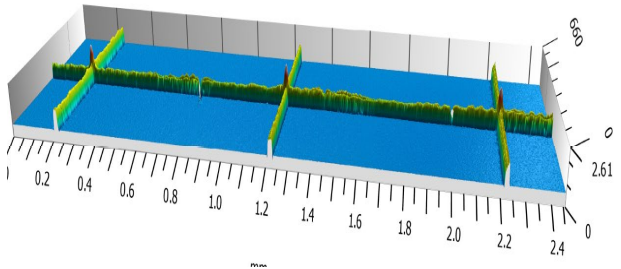
- Transparent conductive substrates – away from TCOs

  Printed novel transparent hierarchical micro-/nanomesh electrodes:
  - We target a solar transmittance above 80%, and a sheet resistance below 10 ohms/sq
  - Electrochromic window system demonstrator with the dimensions in the order of 6 cm x 6 cm, switching time in the range from 1 min to 3 min

- Printed embedded components
  Sensors

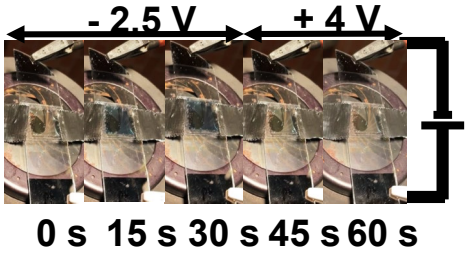
Aerosol jet printing for prototyping





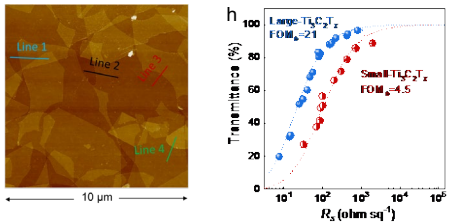
WP 4 & 5 Applications

- VIS-NIR switchable Pt-mesh based electrochromic device



"Electrochromic device with hierarchical metal mesh electrodes: transmittance switching in the full spectral range of solar radiation", submitted to Solar Energy Materials and Solar Cell

- Transparent conductive electrodes



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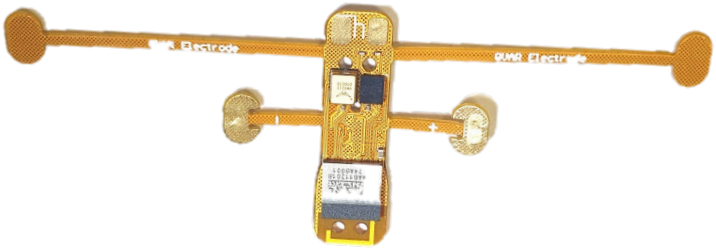
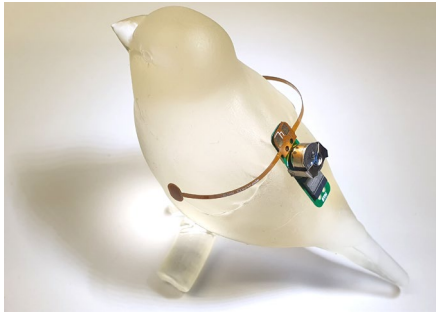
- TinyBird Challenges





Thank you for your attention!

Please visit our booth for more information!