EPFL

Strategic Focus Area
Advanced Manufacturing

MICROFLUIDICS: Functional Integration for rapid realization of microreactors and bio-assays

Vivek Subramanian, EPFL
Andrew deMello, ETHZ
Patrik Hoffman, EMPA
Yaroslav Romanyuk, EMPA
Helmut Schift, PSI

École polytechnique fédérale de Lausanne

ETH zürich EPFL PAUL SCHERRER INSTITUT PSI Empa Materials Science and Technology

EPFL

Organization and Teaming Status

Strategic Focus Area
Advanced Manufacturing

EPFL
Materials, Extrusion Printing, and integration

Lead: Vivek Subramanian
Postdoc: Babak Mazinani (Glass development)
PhD student: Mustafa Fadlelmulla (PZT development)

ETH zürich
Demonstrator Integration, Design Specification

Lead: Andrew deMello
Scientist: Stavros Stavrakis

Empa
Materials Science and Technology
Low-temperature sintering
Embossing materials support

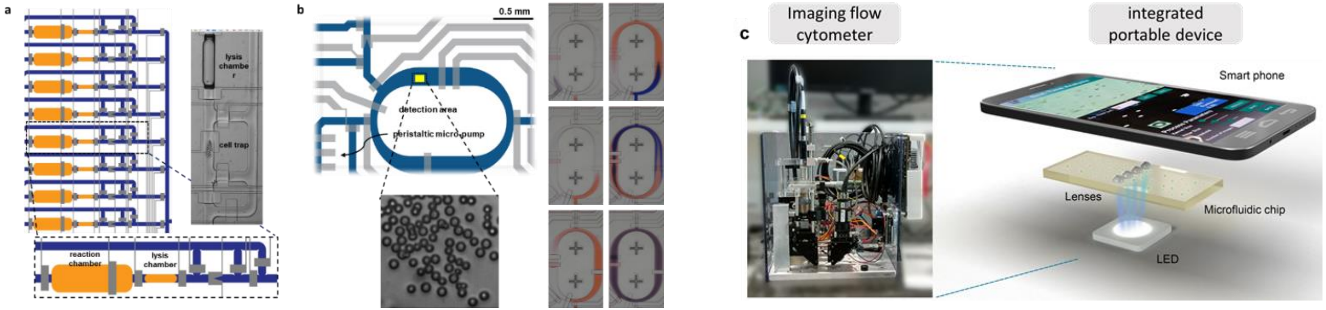
Lead 1: Yaroslav Romanyuk (Photonic Sintering)
Scientist: Evgeniia Gilshtein (Photonic Sintering)
Lead 2: Patrik Hoffman (Materials for embossing)

PAUL SCHERRER INSTITUT
PSI
Embossing

Lead: Helmut Schift
Postdoc: Muhammad Refatul Haq

Vision and Goals

Strategic Focus Area
Advanced Manufacturing



What?

- Manufacturing technology for integrated microfluidics
  - Active elements,
  - gold-standard materials
  - integrated control and sensing

Why?

- Glass is king for real applications
- Integration will drive down cost and facilitate adoption for analytics

How?

- Low-temperature materials and processes to allow integration of glass with metals and silicon microelectronics

ETH zürich EPFL PAUL SCHERRER INSTITUT PSI Empa Materials Science and Technology

Plans / Milestones

Materials

- develop a low-temperature printable glass based on a modified phosphate glass. The glass will be water-stable. Peak process temperature will be <400°C. ***Early breakthrough by M24***
- develop a low-temperature printable piezoelectric material based on sol-gel PZT.

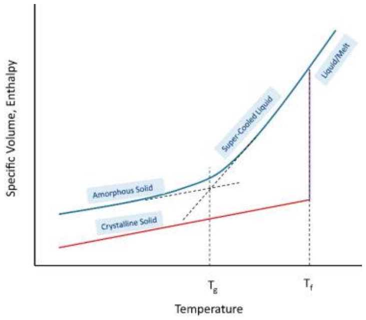
Processes and Integration

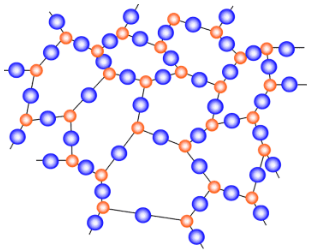
- develop an extrusion printing process to print glass microfluidics on demand. Line-edge roughness and resolution will be characterized and optimized. ***Early breakthrough by M24***
- develop an embossing process for microfluidic-channels, including identification of a proper choice of stamp materials, geometries and processes, and tool modification. ***Early breakthrough by M24***
- explore the feasibility of selective heating of stamps, enabling bonding without structural deformation.
- develop an inkjet + 3D printing-based process for realizing PZT-based valves.
- demonstrate photonic sintering of printed phosphate glasses and PZT valves, including the use of colored dopants to alter absorption as needed.
- explore step-by-step photonic sintering of glass. Thicker layers can be sintered if each light pulse makes the upper layer more transparent, allowing deeper light penetration until the whole layer is sintered.
- use our integrated pick and place technology based on an nscrypt 3D printer with a custom integrated pick-and-place head to attach discrete components within the monolithic fabrication process
- use our existing printed metal technology to fully wire and integrate the platform

Overall Technology demonstrator

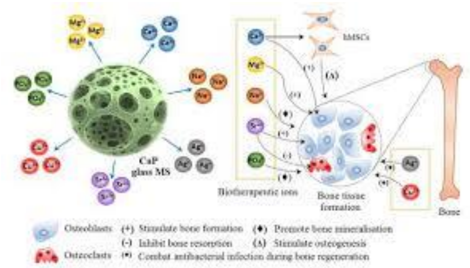
- demonstrate a microfluidic formulator for protein processing based on integrated microfluidics
- demonstrate a programmable microfluidic platform for manipulating single cells. This will integrate conduits, chambers, valves and pumps within a monolithic platform.
- Demonstrate integration of semiconductor components to realize a flow cytometry platform.

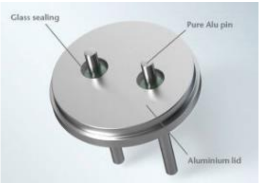
Initial Results: Glass





Phosphate glass





Chemical stabilization of glass

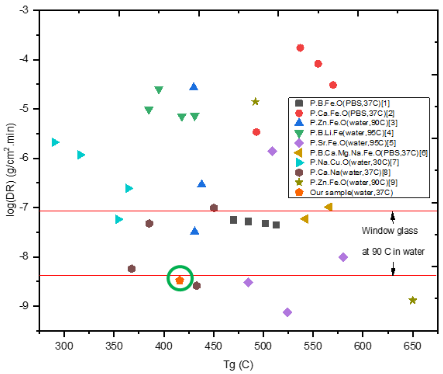
Why Glass?

- Non-porous
- Inert
- Thermally stable
- Material of choice for real biology

Disadvantage: We need a low-T glass

- Compatibility with Silicon Microelectronics
- Compatibility with Metals

Initial results: Glass that processes at <450°C, is water-stable, and ionically non-conductive

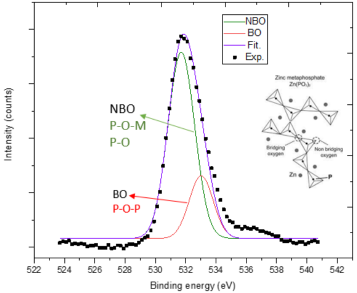


Strategic Focus Area
Advanced Manufacturing

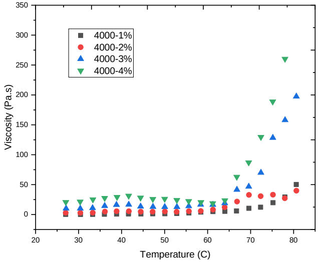
Initial Results: Glass

Strategic Focus Area
Advanced Manufacturing

Glass synthesis

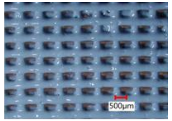


Ink formulation



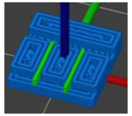
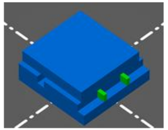
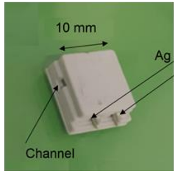
Printing-based Integration

Step 1: Glass

Step 2: Glass + Conductors

Step 3: Glass + Conductors
+ microfluidic channel

ETH zürich EPFL PAUL SCHERRER INSTITUT PSI Empa Materials Science and Technology

Initial Results: PZT Actuators

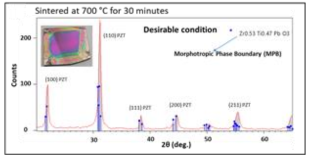
Strategic Focus Area
Advanced Manufacturing

1) Formulation of PZT ink:

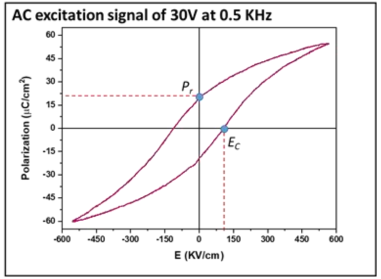
Summary of PZT sol-gel synthesis:

Hydrate lead acetate + alcohol Heating at 120-180 °C for 30 min-2 h	Elimination of water of crystallization, formation of lead acetate $Pb(CH_3CO_2)_2$
Titanium (IV) isopropoxide + alcohol Heating at 84-190 °C for 30 min-2 h	Formation of $Ti(OR)_4$
Zirconium (IV) propoxide + alcohol Heating at 84-190 °C for 30 min-2 h	Formation of $Zr(OR)_4$
Stirring and Heating (distillation) at 120-180 °C for 3-10 h	Formation of Pb-Zr, Pb-Ti double alkoxide. $PbZrO_2(OR)_2$, $PbTiO_2(OR)_2$
Cooling to room temperature	
Addition of solvent	Adjustment of the concentration
Addition of water	Hydrolysis
Stirring and Heating at 120 °C for 12-36 h	Polymerization through a condensation reaction

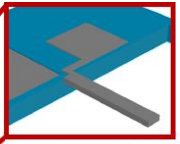
2) Verification of converted film properties:

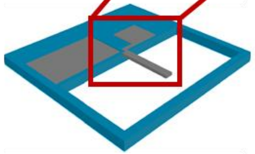


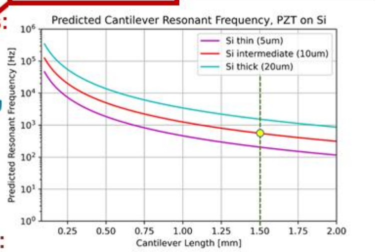
Device structure: Si/Ti/Pt/PZT/Pt



3) PZT cantilever devices:



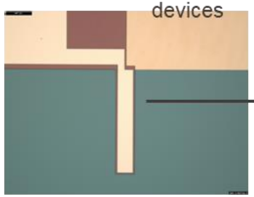


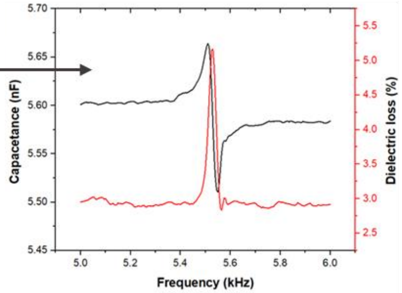


Device config.:

L: 1.5 mm *w:* 255 μm t_{PZT}: 360 nm t_{Si}: 10 μm

Microfabrication of PZT cantilever devices

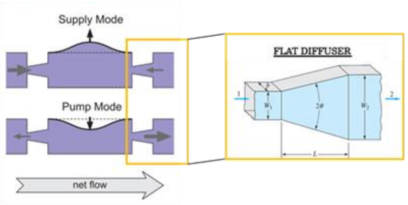


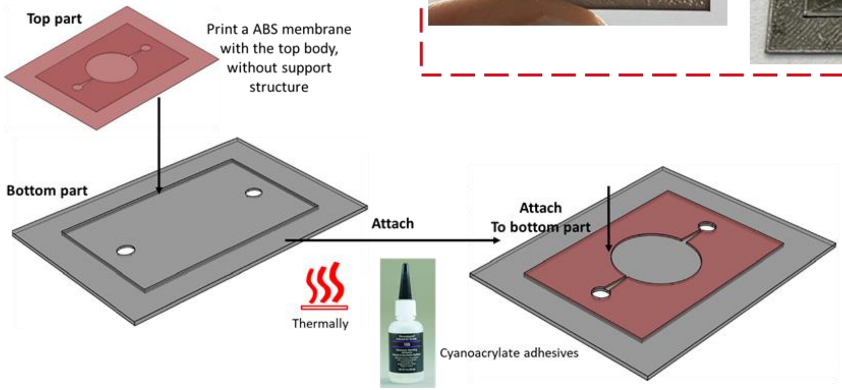


Initial Results: Extrusion printing optimization and modeling

Strategic Focus Area
Advanced Manufacturing

1) Design:





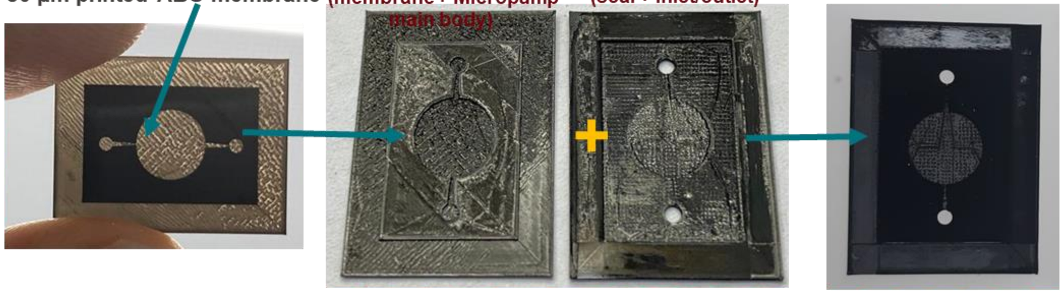
2) Printing of ABS micropump by FDM:

50 µm printed ABS membrane

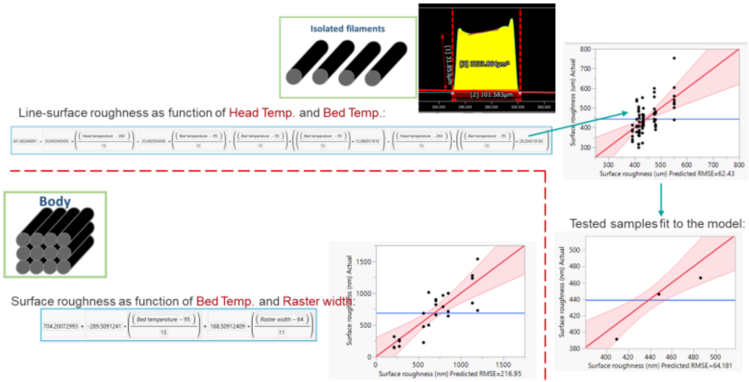
Top part (membrane + Micropump main body)

Bottom part (seal + Inlet/outlet)

Thermally bonded



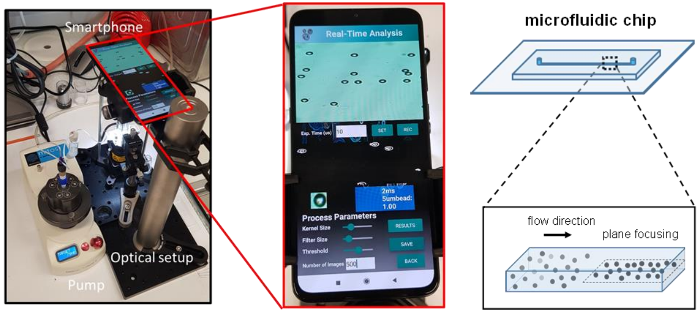
3) Printing of ABS micropump roughness study:



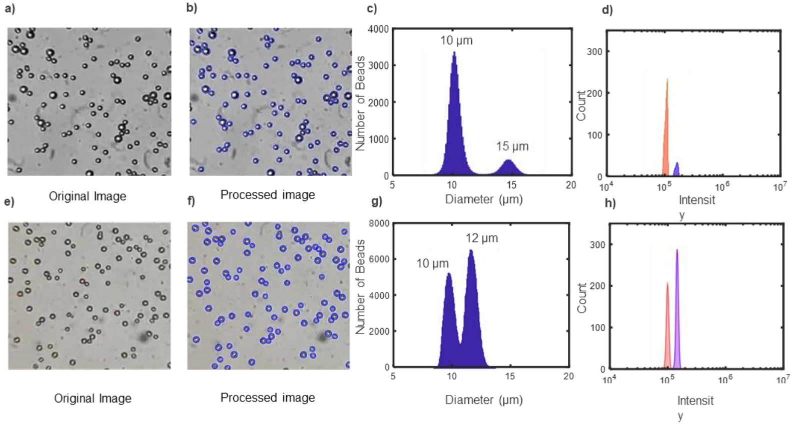
Initial Results: Demonstrator definition

Strategic Focus Area **Advanced Manufacturing**

Smartphone based imaging real time flow cytometry



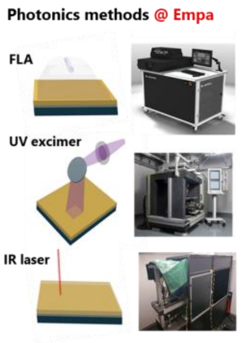
We developed a prototype smartphone-based flow cytometer. This platform incorporates an LED, a microfluidic flow cell for viscoelastic particle plane focusing and uses the built-in camera of a smartphone to track beads in flow. The smartphone-based FC device can detect and enumerate two different bead types in a mixture

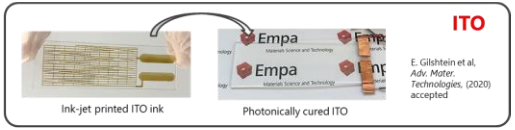


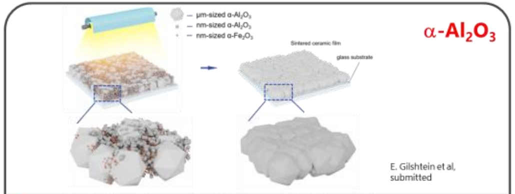
Top part: a) Original image of a mixture of 10 and 15 um beads captured with the smartphone-based imaging flow cytometer. b)The image is then processed in real time for bead size determination. c) After this step a histogram of size vs number of beads can be constructed. d) This result is validated though measurements of fluorescence intensity vs number of beads using a commercial flow cytometer.
Bottom part (e-h): The same sequence of images as in the top part but in the case of 10 and 12 um beads.

Upcoming tasks

Strategic Focus Area
Advanced Manufacturing



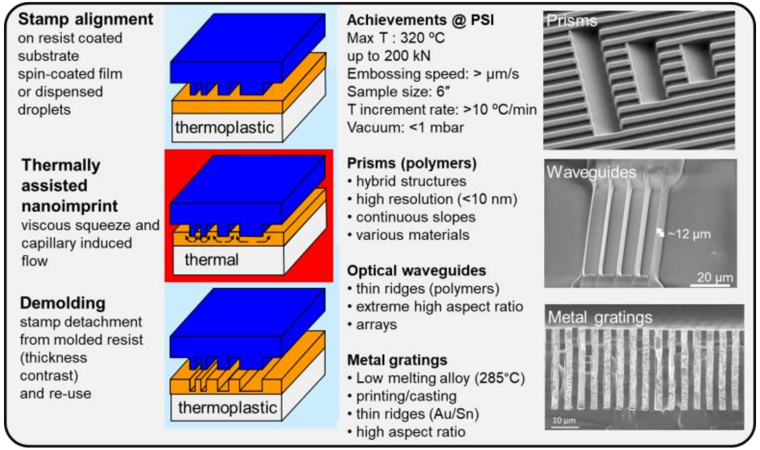




- Colored dyes/dopants enhance optical absorption
- Rapid photonic sintering of oxides on temp-sensitive substrates

Absorption-tuning and photonic curing to allow very low-T processing

The combination of novel materials with hot-embossing allows high-resolution low LER patterns



Summary

Initial Results
- On track with glass materials and PZT, which are key materials for expected early breakthrough
- On track with design of demonstrator to drive integration strategy

Key Upcoming Tasks
- Embossing work has begun… reporting expected next year.
- PZT is ready for deployment in photonic curing… next step is first cross-institute task

Overall
- No deviations to report at this time
- Everything is on track or ahead of schedule