THERMINIC 2018

STREAMS
Smart Technologies for eneRgy Efficient Active cooling in Advanced Microelectronic Systems

THERMOREGULATED MICROVALVE FOR SELF-ADAPTIVE MICROFLUIDIC COOLING

Amrid Amnache[1], L-M. Collin[1], G. Laguna[2], M. Vilarrubi[2], S. Hamel[1], J. Barrau[2] and L. G. Fréchette[1]

[1]UMI-LN2, Universsité de Sherbrooke, 2500 boul. de l'Université, Sherbrooke, Québec, Canada J1K2R1
[2]Universitat de Lleida, Pl. de Víctor Siurana, 1, E-25003 Lleida, Spain

Stockholm, September 26th 2018

Institut interdisciplinaire d'innovation technologique

Universitat de Lleida

iberus CAMPUS DE EXCELENCIA INTERNACIONAL

UNIVERSITÉ DE SHERBROOKE

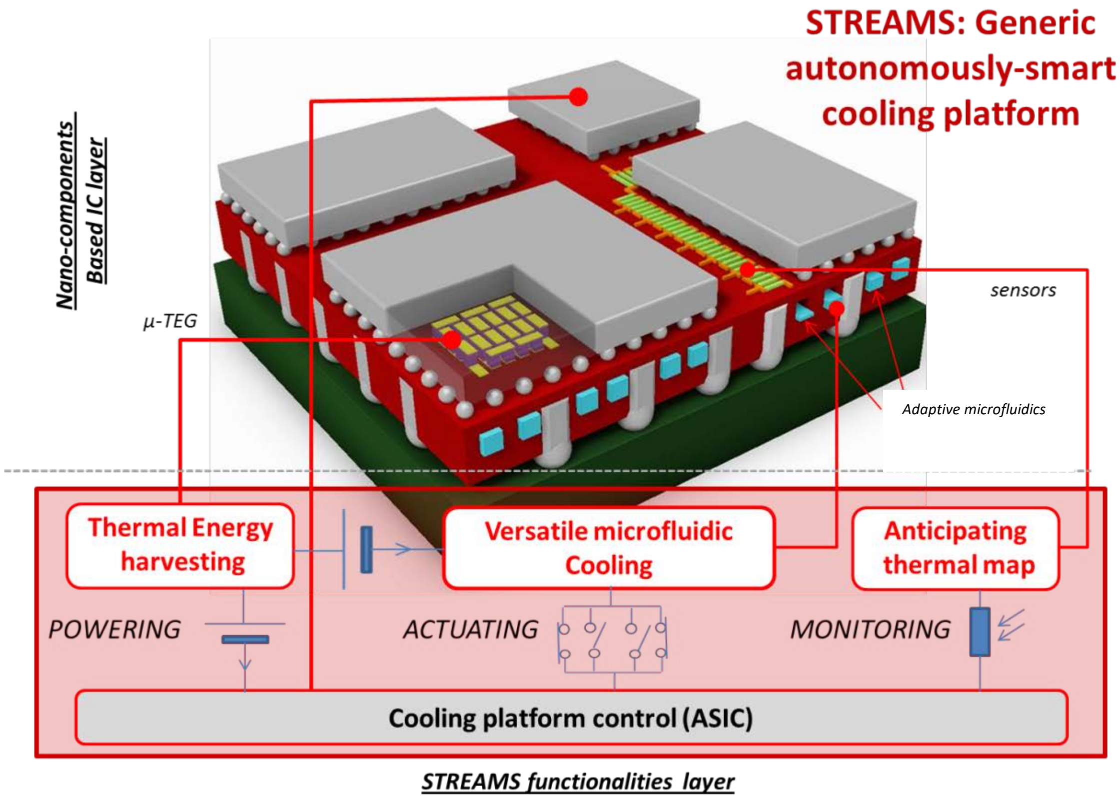
Outline

- Interest for liquid cooling
- Microvalves for Self-adaptive microfluidic cooling
    - Microfabrication process
    - Fluidic performances
- Conclusion

STREAMS European project

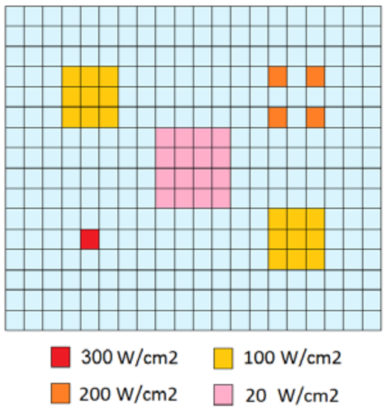
Intelligent thermal management in 3D

Approach: combine adaptive microfluidics with thermoelectric temperature mapping and energy harvesting into an interposer or 3D stack



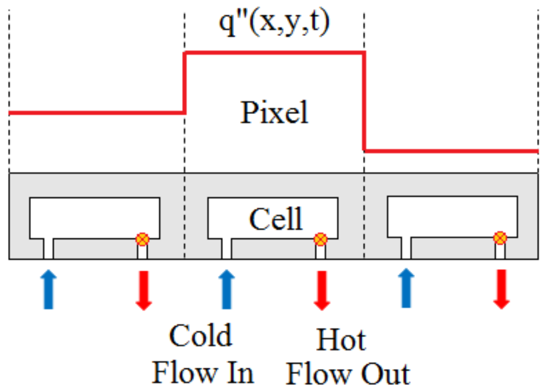
Cell Array for distributed cooling

1. Discretize the interposer into cells



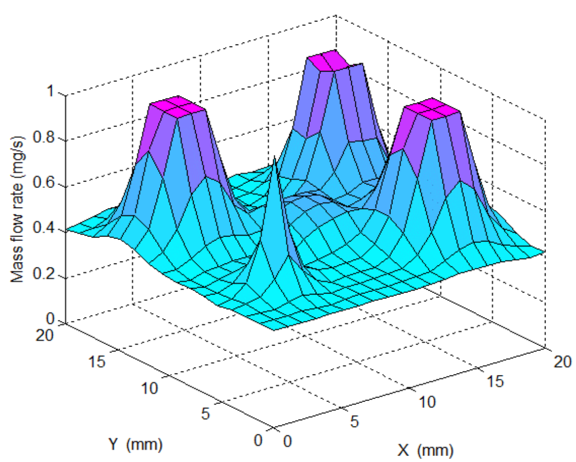
Thermal map

2. Each cell individually cooled (massive parallel configuration)

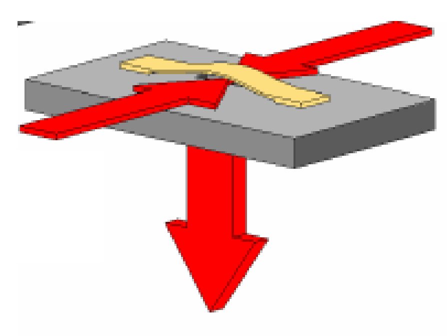


4. Tailored cooling for optimal cooling performance

$\dot{m}$



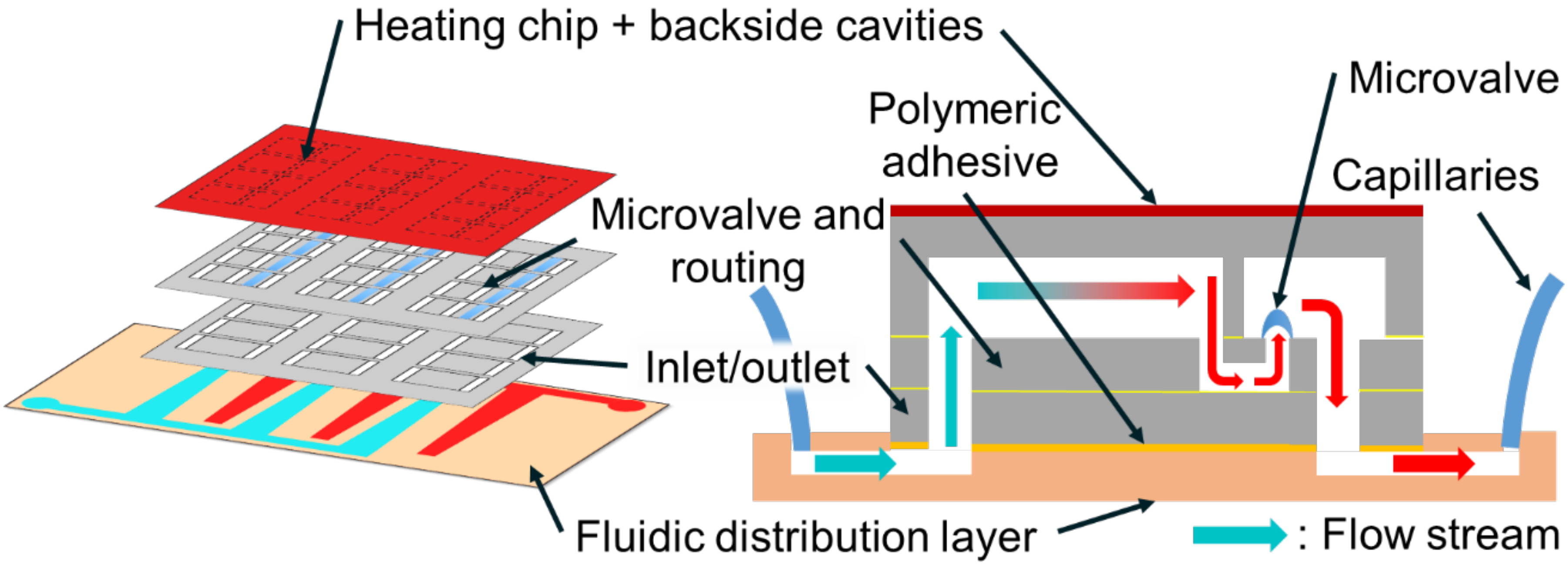
3. Valve controls coolant flow in each cell



H. Azarkish et al., *ITherm 2017*

M. McCarthy et al., *J. MEMS*, 2008

Microvalve integration

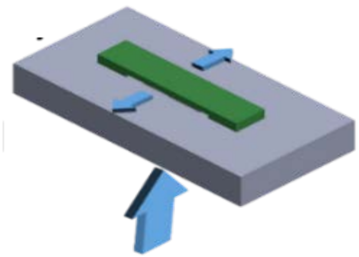


Stacking **Cross section of one cooling cell**

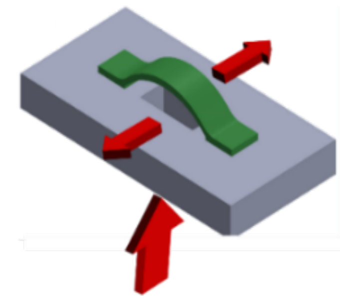
The microvalve is heated by the fluid locally:

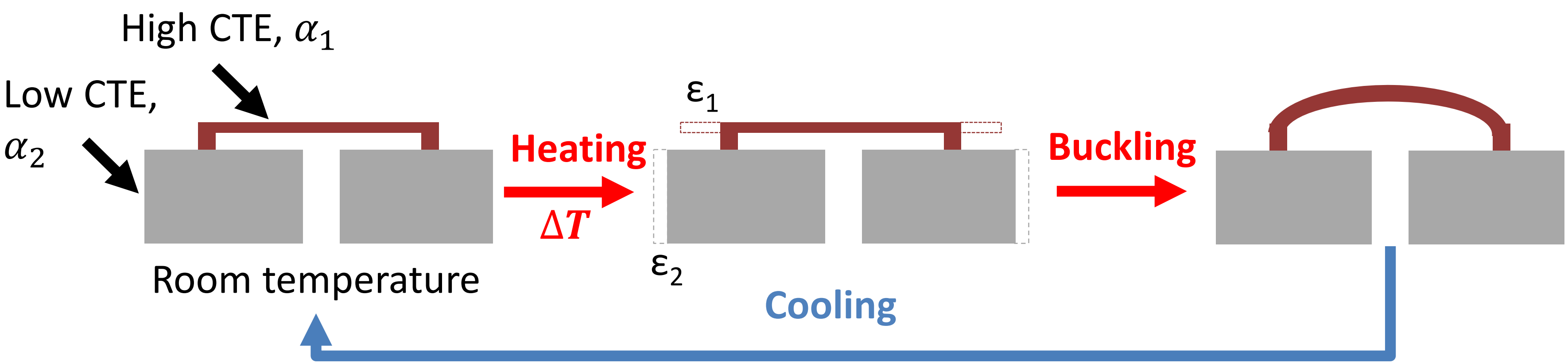
- Sensing the temperature
- Actuated by heat

Thermoregulation principle of the microvalve



Passive thermoregulation



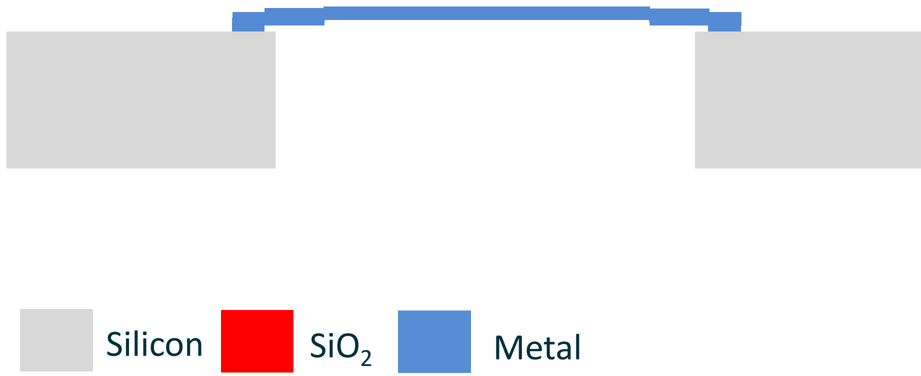


$$\begin{cases} \varepsilon_1 = \dfrac{\sigma_1}{E_1} = \alpha_1 \Delta T \\ \varepsilon_2 = \dfrac{\sigma_2}{E_2} = \alpha_2 \Delta T \end{cases} \Rightarrow \varepsilon_{tot} = \varepsilon_1 - \varepsilon_2 = (\alpha_1 - \alpha_2)\Delta T \Rightarrow \Delta T \uparrow \rightarrow \varepsilon_{tot} \uparrow \rightarrow flow\ rate \uparrow$$

For a fixed Δ*T*, high Δα gives large deformation

Fabrication of microvalves

Microfabrication process flow

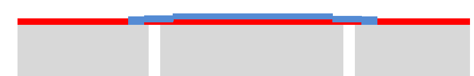


a) PECVD of 2 µm of SiO_2 on Si wafer

b) RIE of 0.7 µm of SiO_2 (eccentrities)

c) RIE of 1.3 µm of SiO_2 (anchors)

d) Deposition of 9 µm of metal and Lift-off



e) DRIE of 450 µm of Si (flow inlet)

f) Releasing by wet etching of SiO2 with BOE

Microfabrication techniques:

- Plasma enhanced chemical vapor deposition of SiO_2 (PECVD)
- Photolithography (4 photomasks) / Lift-off
- Reactive ion etching of SiO_2 (RIE)
- Metal deposition
- Deep reactive ion etching of Si

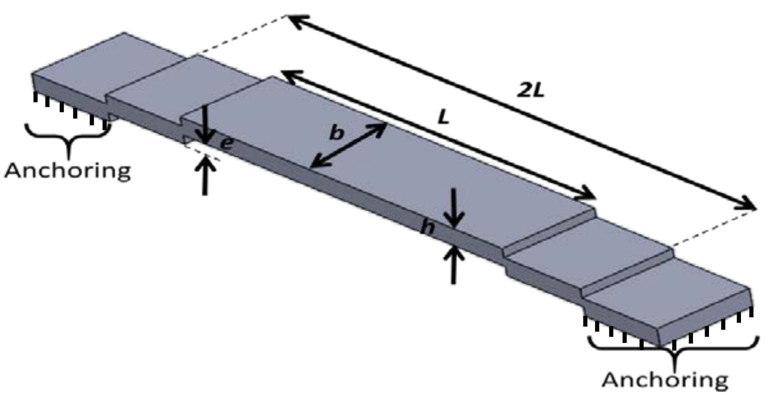
Design and material selection

Material selection based on

- ✓ Coefficient of thermal expansion compared to Si (CTE_{Si} = 2.6 µm/°C)
- ✓ Simplicity of fabrication (PECVD deposition, electroplating, evaporation…)
- ✓ Mechanical properties and compatibility to water

Material	CTE (µm/°C)	Sacrificiel layer	Bonding at high temperature	Other
Ag	19	SiO_2	Yes	No residual stress (evaporation)
Au	14	SiO_2	Yes	Costing
Sn	22	Photoresist	No	Low fusion temperature
Ni	13	Photoresist	No	

Microvalve geometric variables



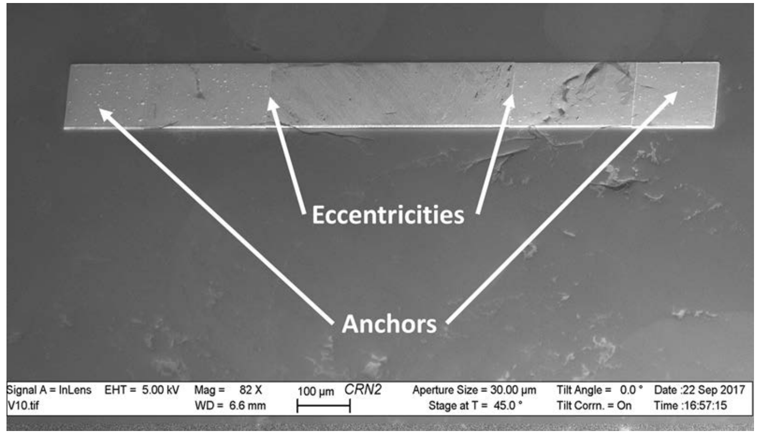
Valve design

Valve	#1	#2
L	1733 µm	2000 µm
e	0.7 µm	0.7 µm
h	9 µm	9 µm
b	250 µm	250 µm

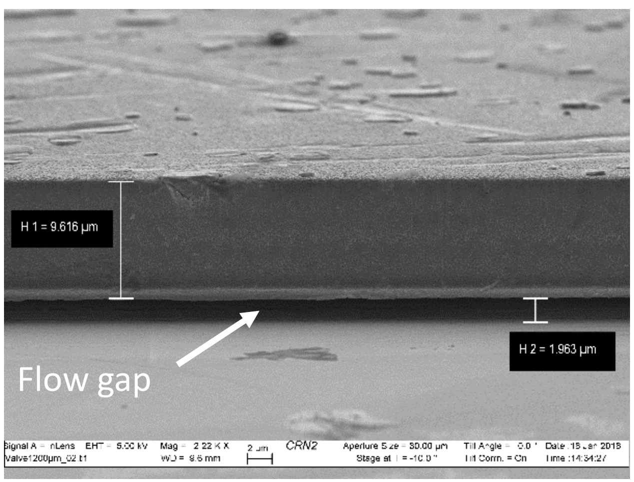
Dimensions based on M. McCarthy et al., *J. MEMS*, 2008

Fabrication of µValves

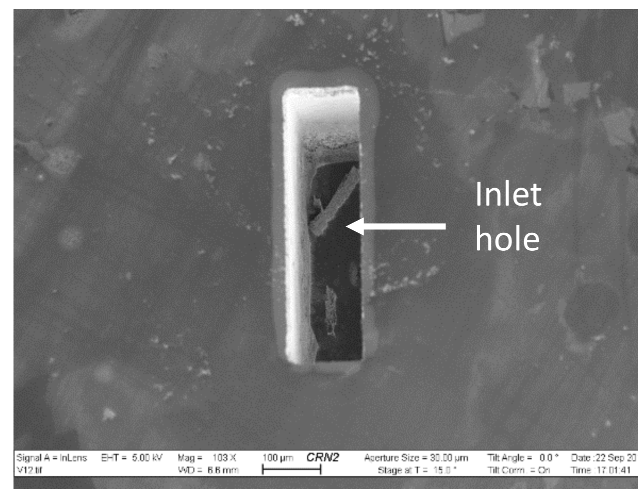
Scanning electron microscopy images of the released microvalve



Top view



Cross section view



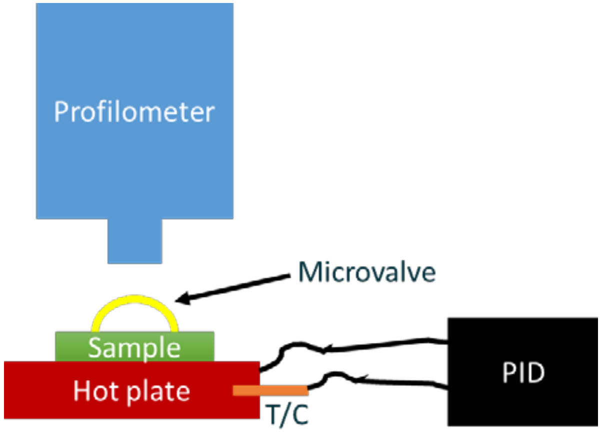
Bottom view

Process flow gave dimensions close to the one in the design phase

Experimental characterization

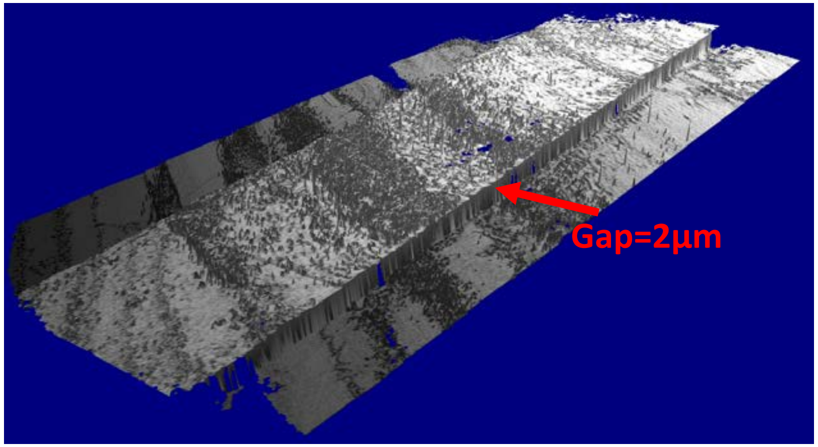
Optical profilometer characterization

- To measure the topology at room temperature
- To observe the geometry shift in function of the temperature

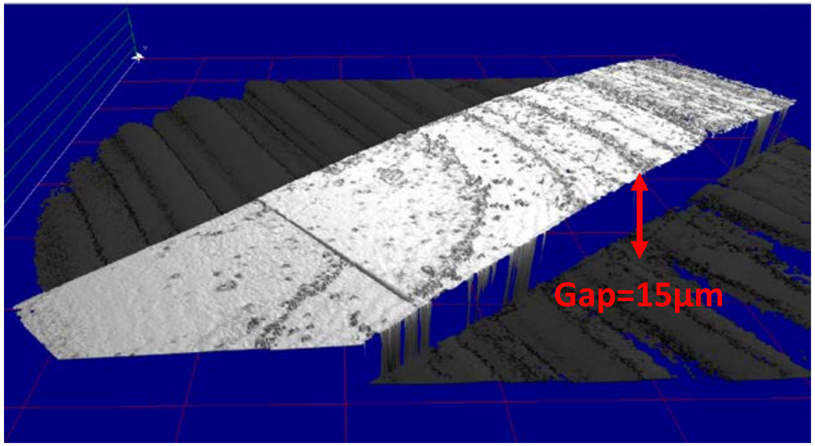


Setup for valve deflection measurement

Flat valve at room temperature (2000 µm)

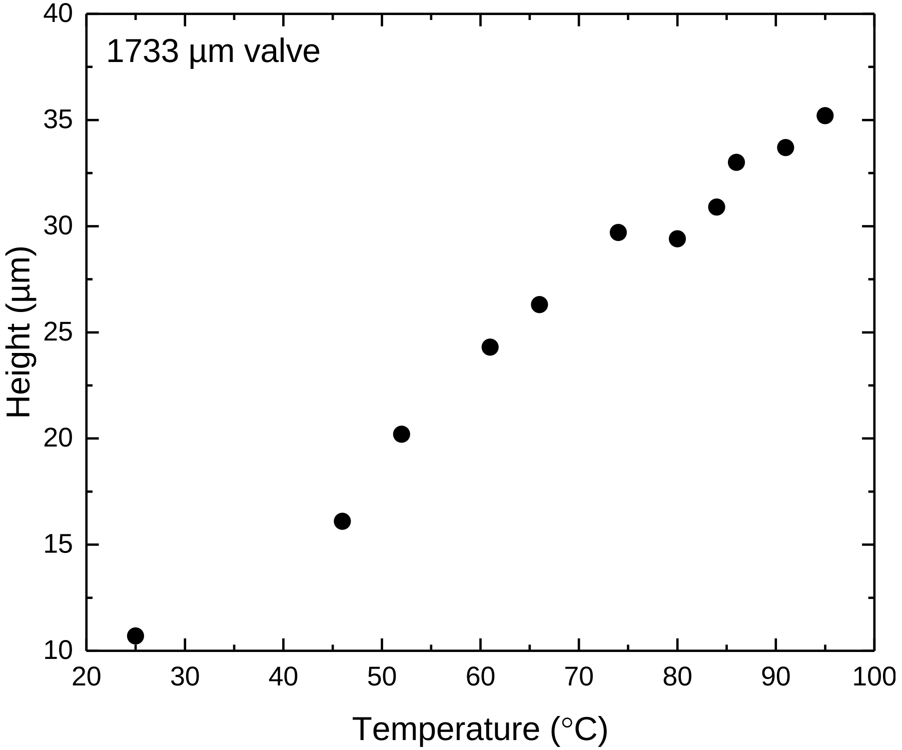


Curved valve at 80°C

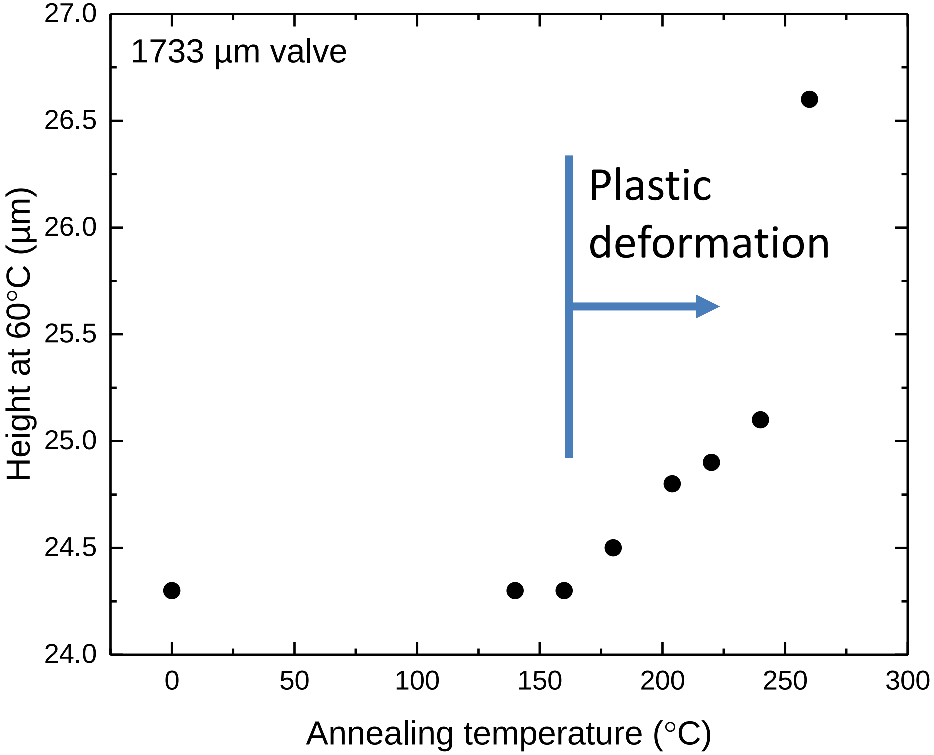


Microvalve deflection measurements

Top height of the 1733 µm valve in regard of the hot plate temperature



Top valve at 60 °C after being exposed to a peak temperature



Gap Over 1000 % the initial value

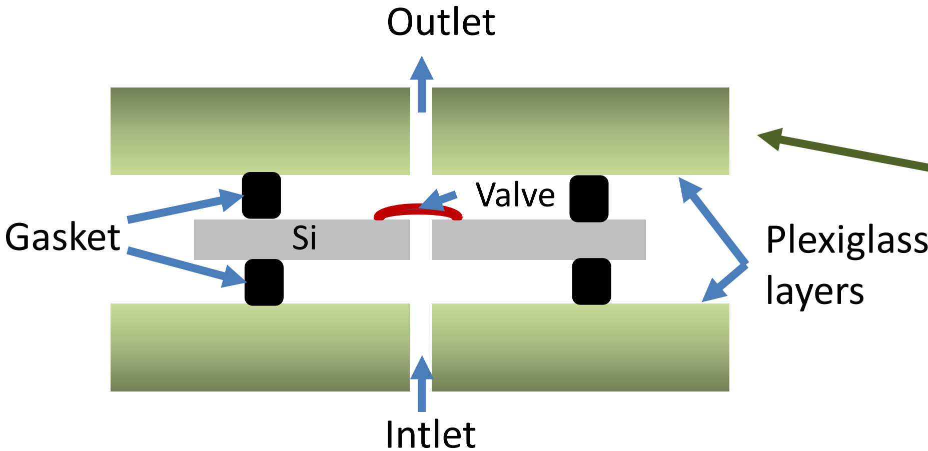
Safe operating range ≤ 160°C

Experimental characterization

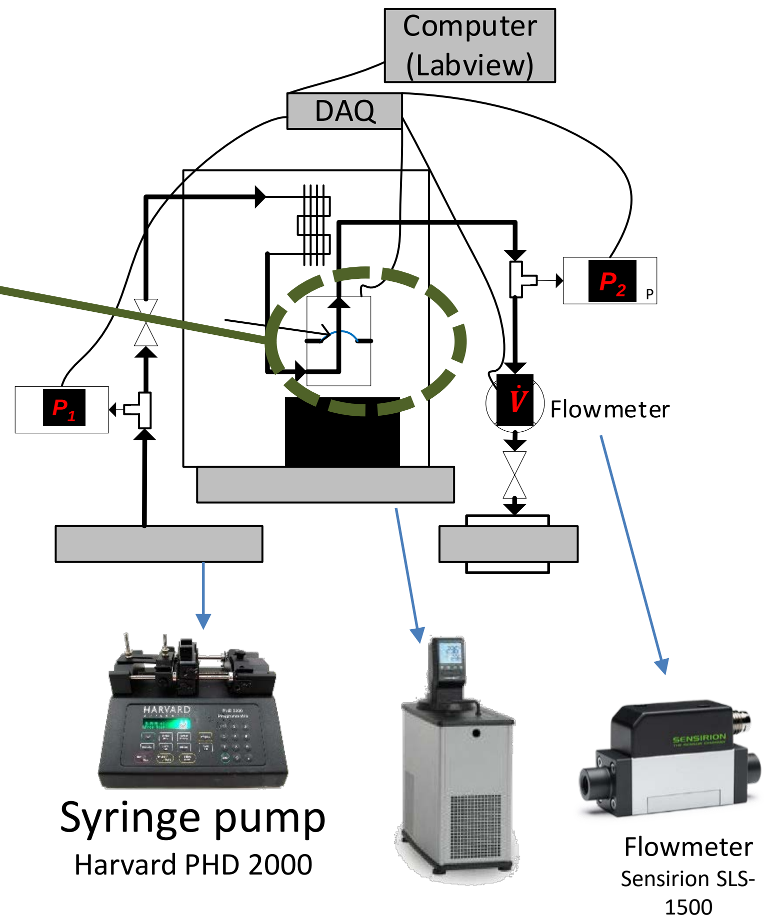
Objectives and methods

- To evaluate the thermofluidic response of the microvalves
- To measure the pressure drop across the microvalve, varying:
  - Masse flow rate
  - Temperature

Pod cross-section



Thermofluidic test bench for microvalves



Challenges

- Purging tubing of the bubbles to avoid flow obstruction at the valve
- Flow is pushed from below the valve rather than from its above (better stability)

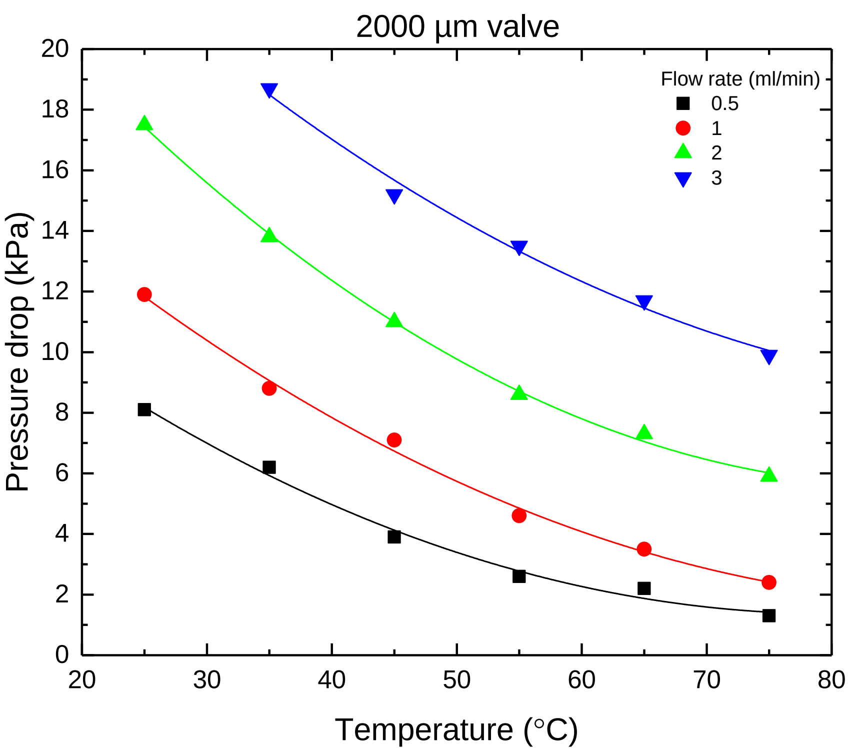
Experimental characterization

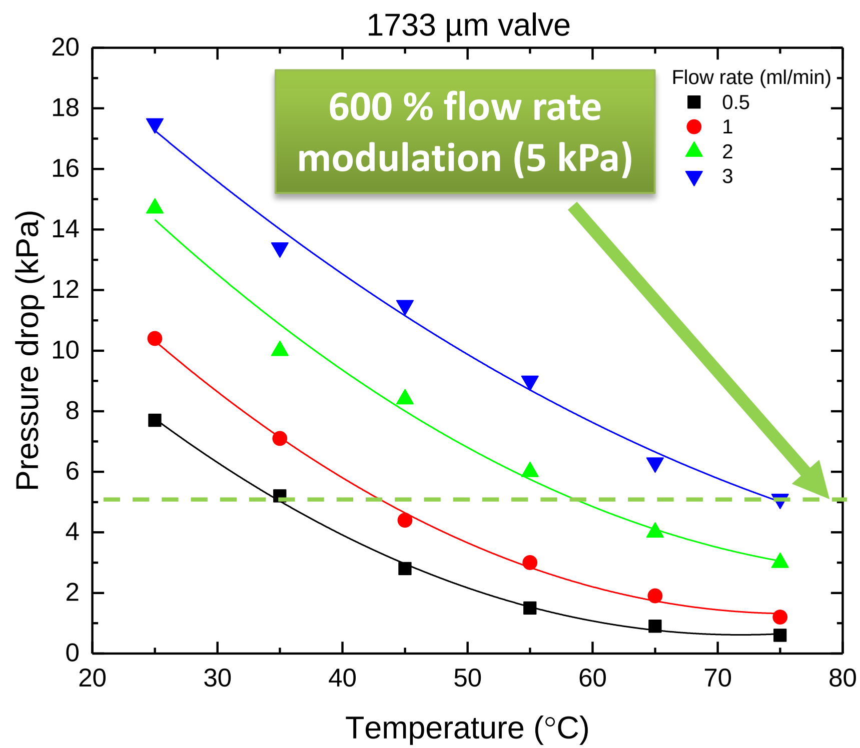
Fluidic performances

- Pressure drop across the canalisation (without valve) is 0.3 kPa at 3 ml/min
- Measurement errors
  - Pressure drop = 0.54%
  - Flow rate = ±10%
  - Temperature = ± 2.2 °C

Thermoregulation is demonstrated

Pressure drop correlation to the temperature and the flow rate





Conclusion

- Microvalves made of silver have been successfully fabricated by MEMS fabrication methods.
  – First demonstration of temperature-driven self-adaptive microvalves in liquid

- Significant deflection was observed. The opening height goes from 2 (25°C) to 25 µm (95°C). This represents over 10 X the height of the initial opening

- Operating range up to 160 °C

- It is possible to control the flow rate from below 0.5 ml/min to 3.0 ml/min for a temperature range of 25 to 75 °C and an operating pressure drop of 5 kPa

- It opens the way of a better heat management in an ever more complex chip heterogeneity:
  - inherent temperature-driven passive control
  - zero power consumption adaptation
  - no added complexity for large cooling matrix

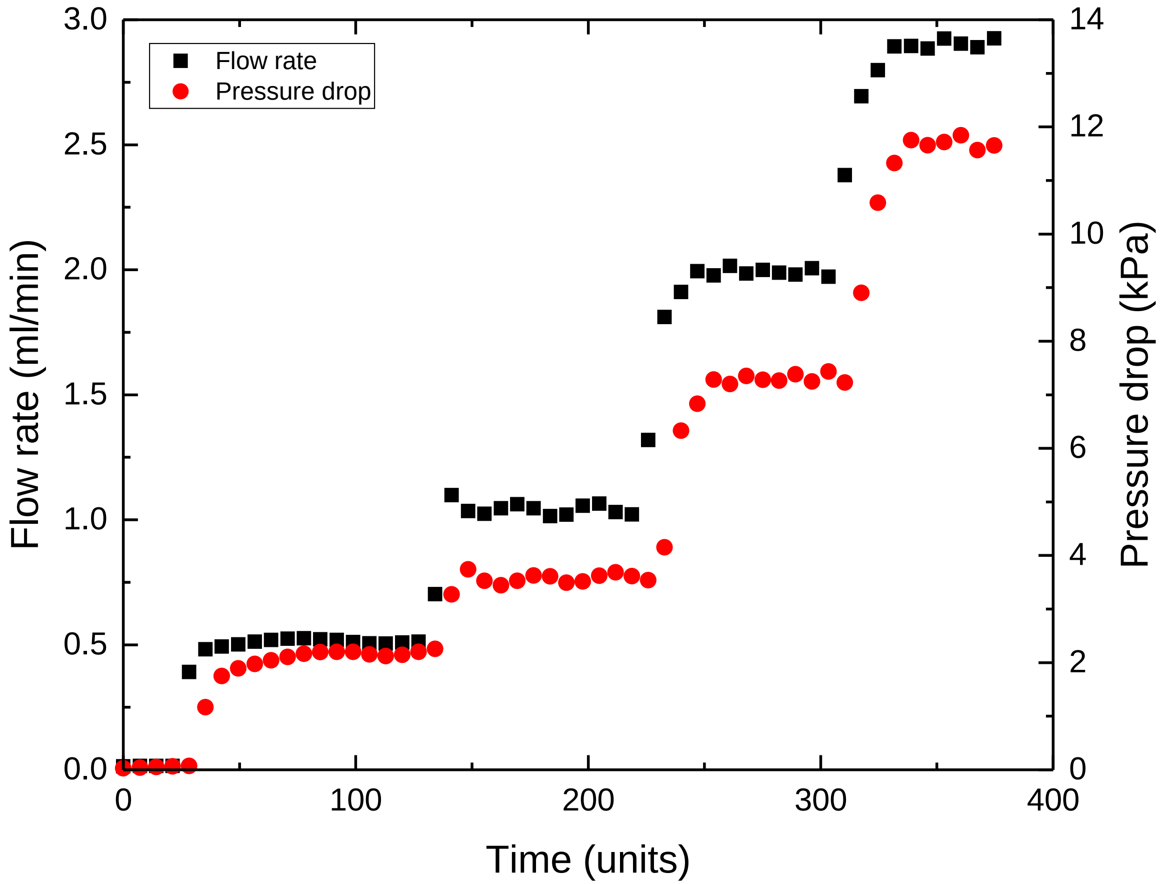
Acknowledgment

- European commission H2020 program
- Ministère économie, science et innovation du Québec

Fluidic characterization procedure

1. To make sure that the valve and the flow stream are at a specific temperature
2. To fixe a flow rate
3. To measure the pressure drop

- ✓ Temperature range: 25 to 75°C
- ✓ Flow rate range: 0.5 to 3 ml/min



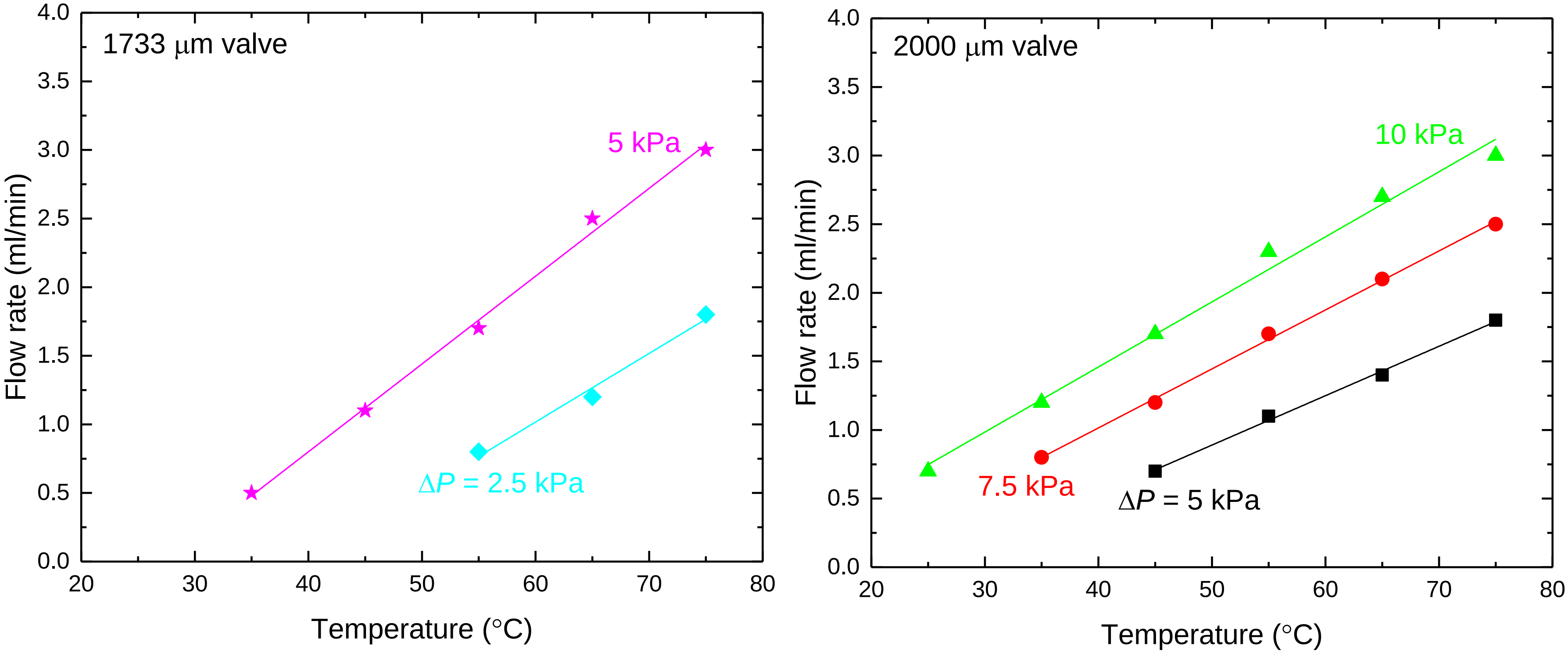
Fluidic measurements of the 2000 μm valve at 65 °C

Experimental characterization

Fluidic performances

- Interpolated flow rate in function of the temperature from the data
- Fixing Δ*P* through a valve and varying flow rate in function of temperature

✓ A wide range of flow rate in function of the temperature (0.5 to 3 ml/min for 25 to 75°C)
✓ The 1733 µm long valve has a steeper slope than the 2000 µm one
✓ Sensitivity = 0.0625 ml/°C



Interpolation of the flow rate in function of the temperature for different pressure drop in 2000 µm and 1733 µm long valves