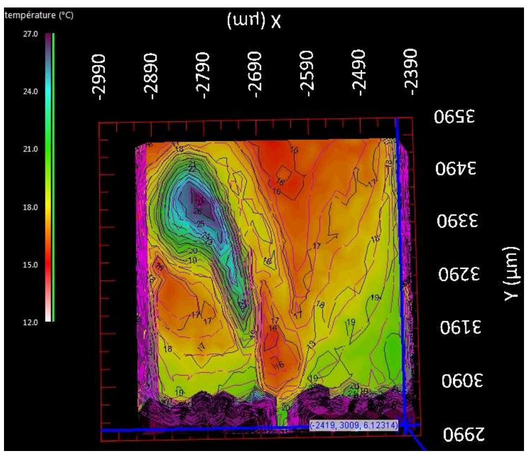
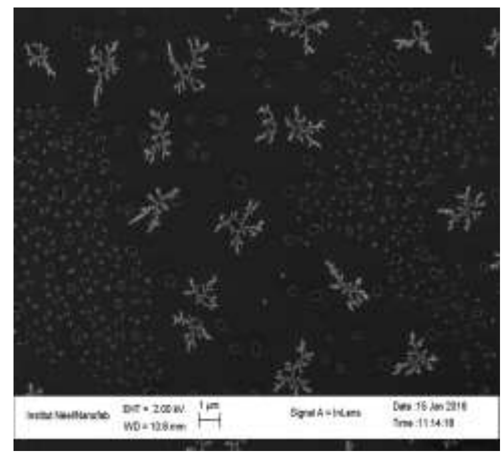
Cavitation hydrodynamique ‘sur puce’

et histoires de bulles

Aspects fondamentaux → **appliqués**

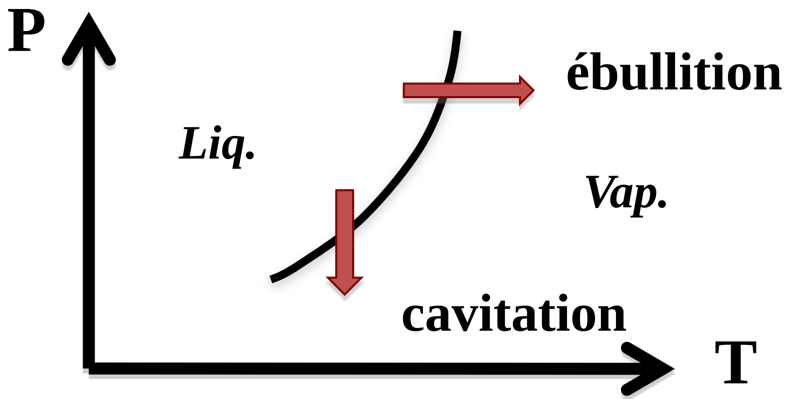
nanosciences - µ nano technologies





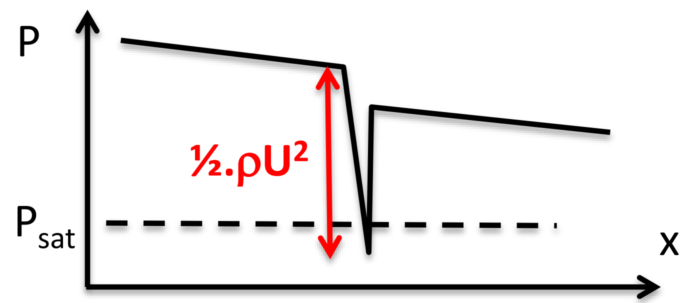
F. AYELA, LEGI
2010 ->
et avec **M. Medrano**, P.J. Zermatten, M. Mohan, S. Mossaz, **D. Colombet**, X. Qiu, W. Cherief

Cavitation

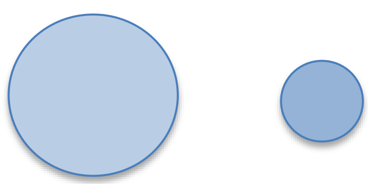


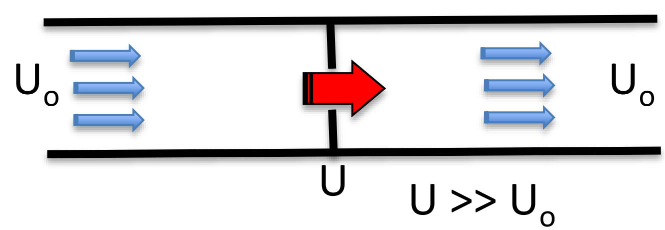
acoustique (ultra sons)

hydrodynamique (Bernoulli)



Autre définition + g^{ale} : ↗ et ↘ d'une bulle





eau : $1/2\rho U^2 = 1$ bar <-> U = 14 m/s

Plusieurs questions

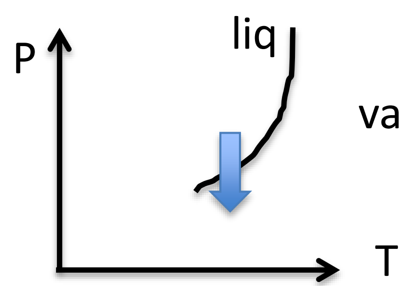
mécanique (onde de choc, érosion)

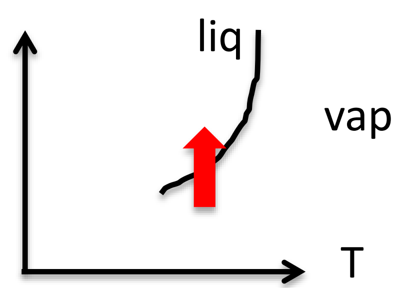
physique : sonoluminescence : **multi bulles (MBSL)**
mono bulles (SBSL)

chimie : sonochimie

taille et forme des bulles
gaz dissous

effets thermodynamiques





$\Delta T = B.\ \Delta T^{\bullet}$ avec $\Delta T^{\bullet} = \rho_v L_v / \rho_l c_l$

↑

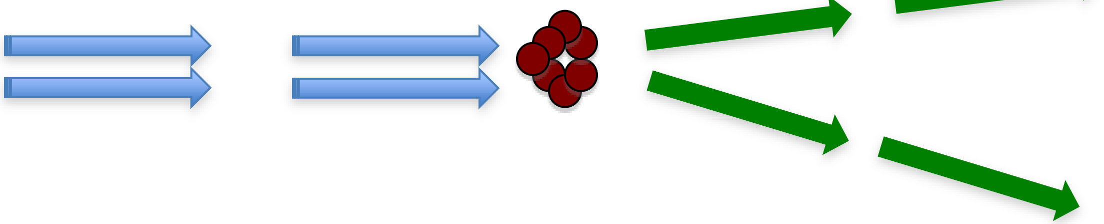
$\Delta T^{\bullet}_{eau} = 0{,}01$ K

$\Delta T^{\bullet}_{N2} = 0{,}6$ K   paramètre B = F(modèle)

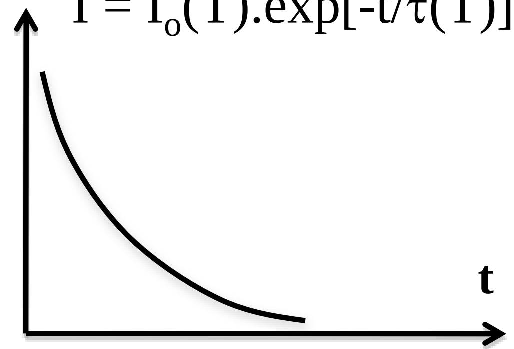
encore jamais mesuré directement

Mesures thermiques locales (collaboration ILM Lyon)

idée : nanoparticules thermofluorescentes

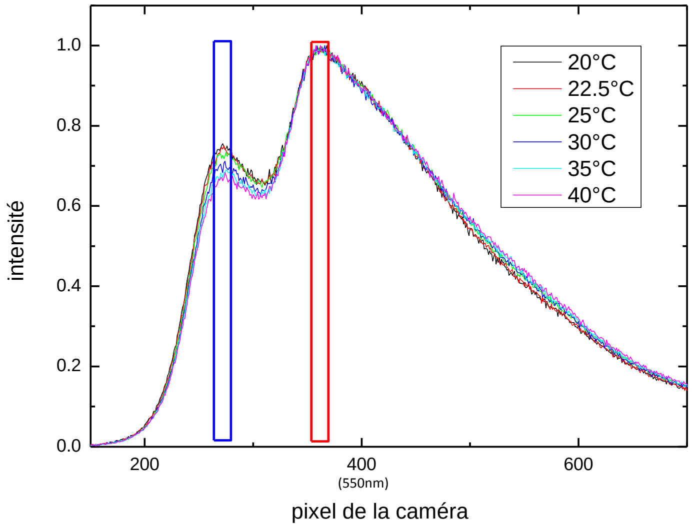


$$I = I_o(T).\exp[-t/\tau(T)]$$



microscopie confocale

3 directions de l'espace

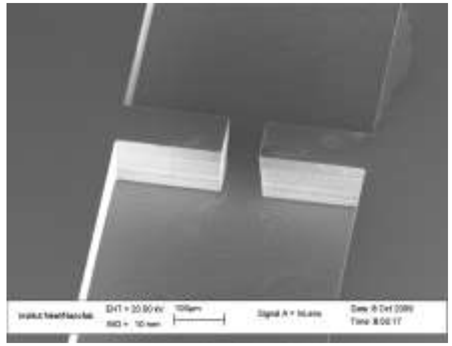


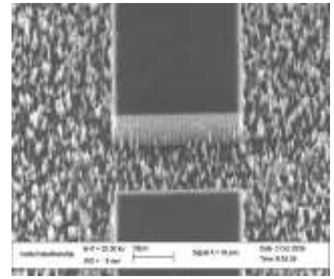
➡ réduction de taille du système (= microsystème fluidique)

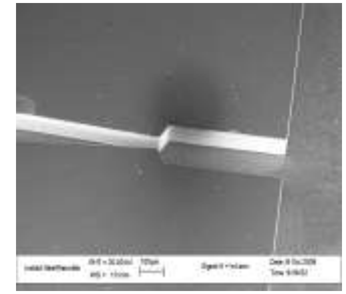
cavitation hydrodynamique 'sur puce'

Différentes géométries

- micro diaphragme
- micro venturi



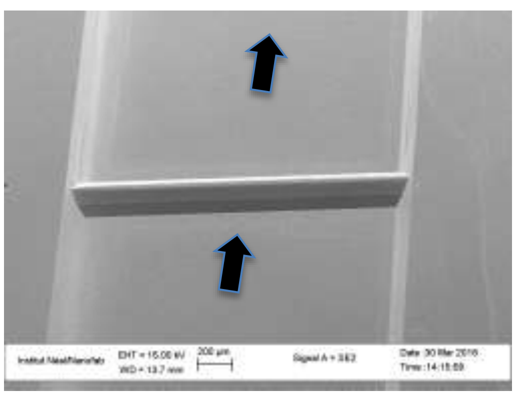


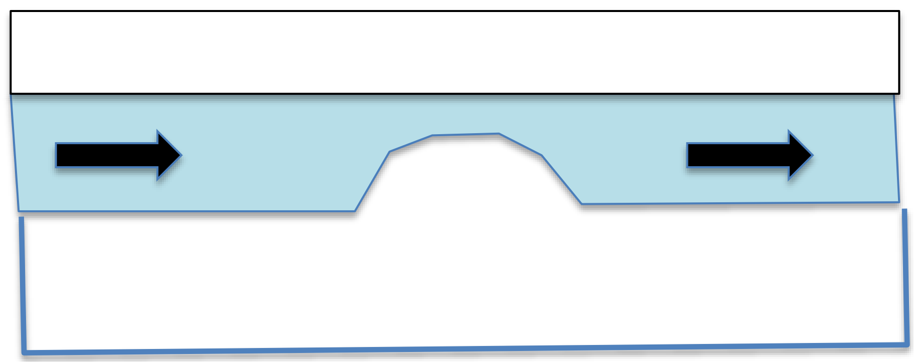


(deep reactive ion etching)

$Q_{cav} \approx$ 1 l/h pour $\Delta P \approx$ 5-6 bars (diaphragme)
$\Delta P \approx$ 3 – 4 bars (venturi)

- micro marche

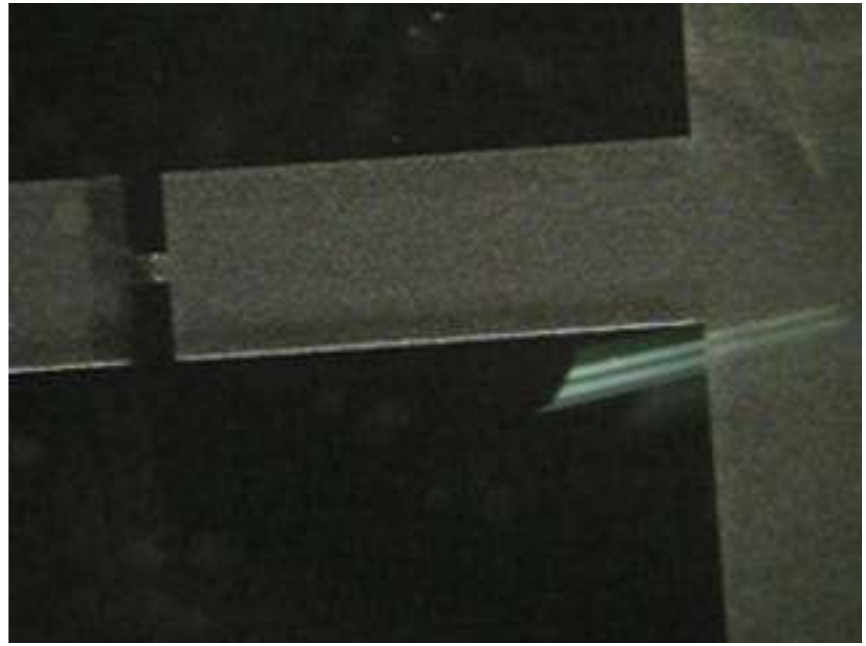




$Q_{cav} \approx$ 5-10 l/h pour $\Delta P \approx$ 5-8 bars

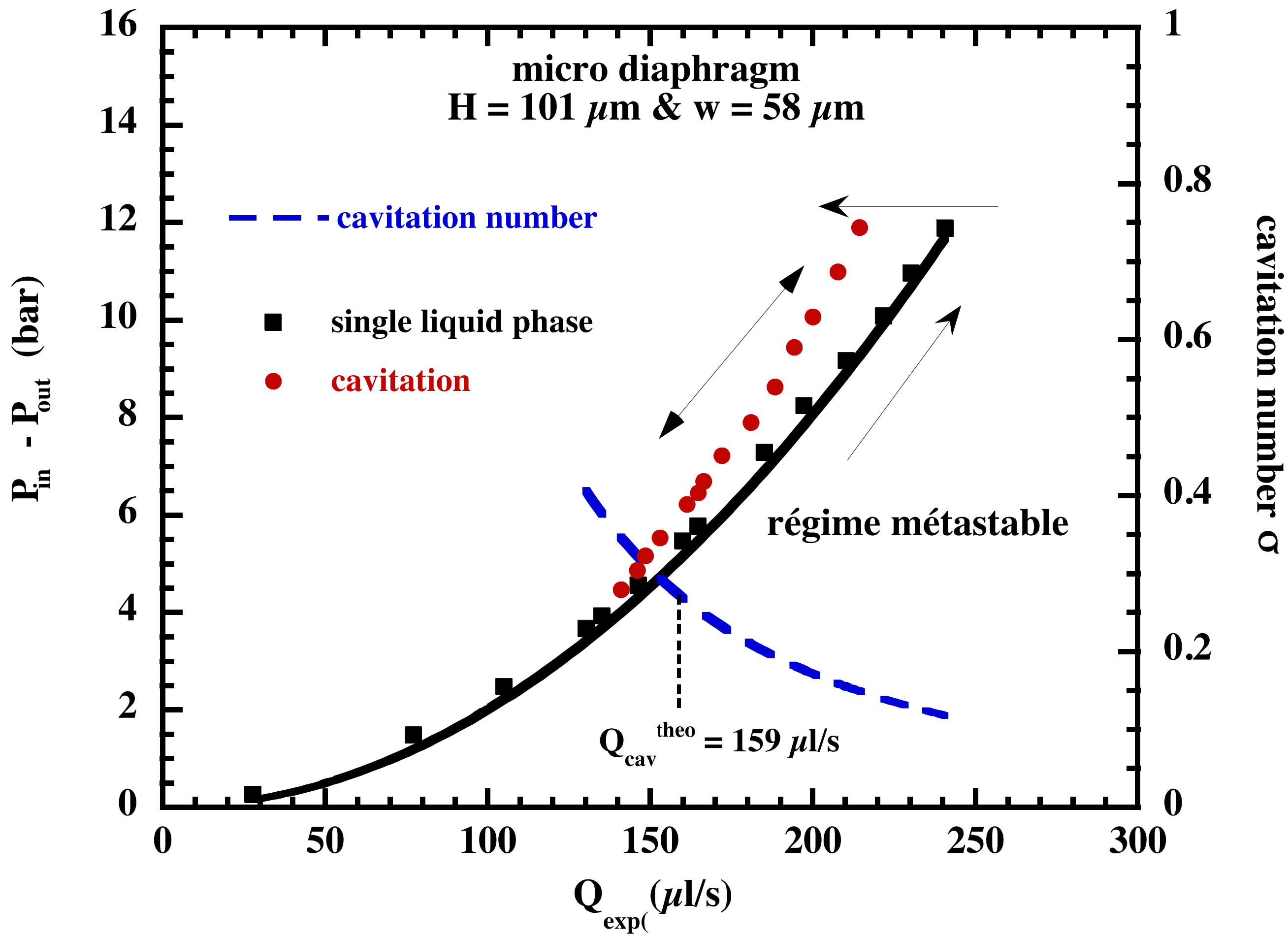
(gravure KOH)

ΔP = 14,6 bars
P_{out} = 1 bar
Q ≈ 1liter/hour
DI water
25 frames / s

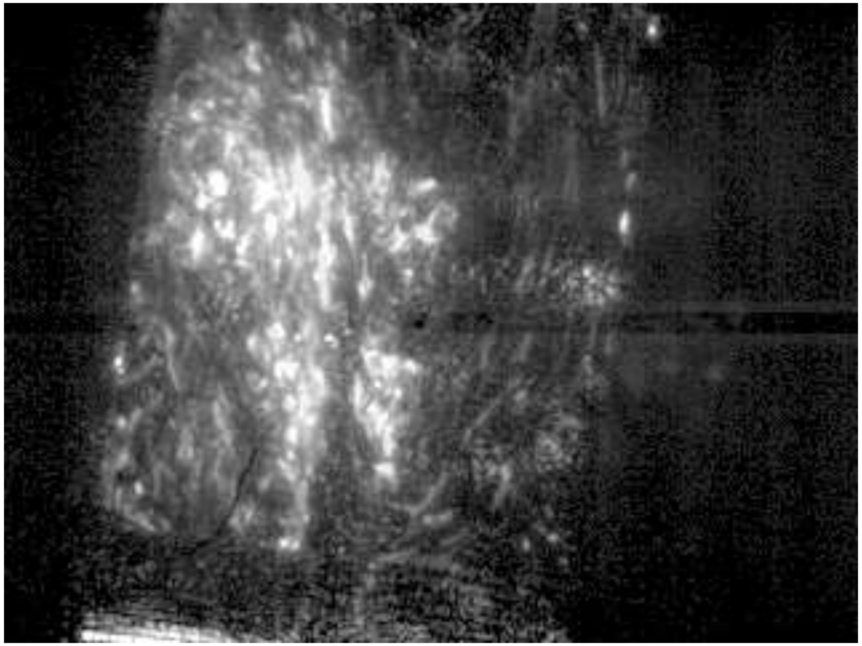


130 µm

1 mm

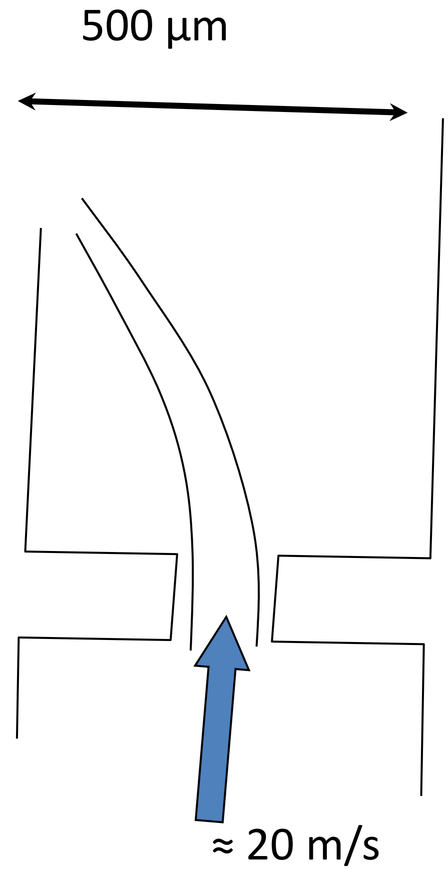


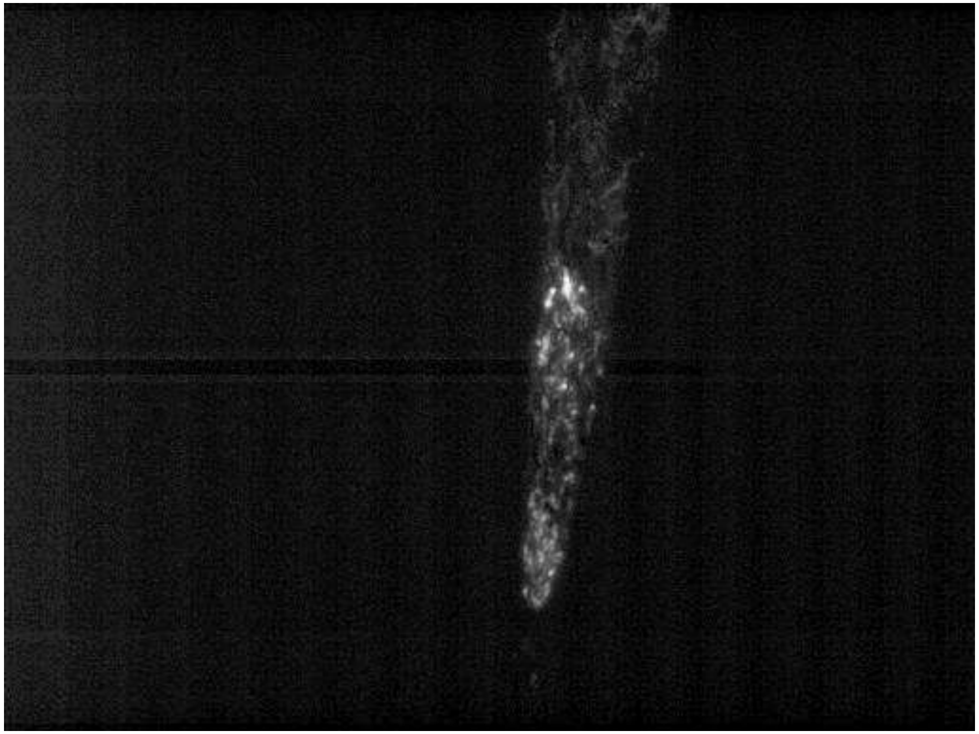
micro diaphragm
H = 101 μm & w = 58 μm
cavitation number
single liquid phase
cavitation
régime métastable
Q_cav^theo = 159 μl/s
P_in - P_out (bar)
cavitation number σ
Q_exp((μl/s)
0
2
4
6
8
10
12
14
16
0
50
100
150
200
250
300
0
0.2
0.4
0.6
0.8
1



54000 frames / second

Slow motion = 1/7000
Real time = 8 ms



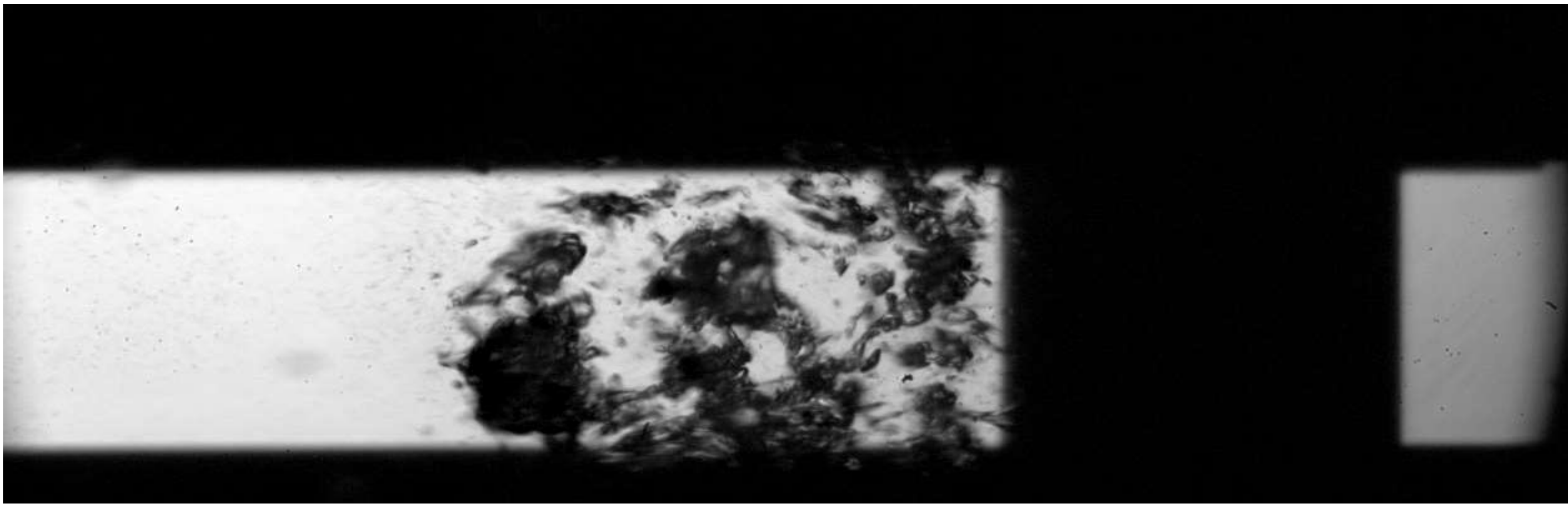


$St_1 = f_1 . L_{cav}/u_o =$ temps jet réentrant /période oscillations ($4\ 10^{-2}$)

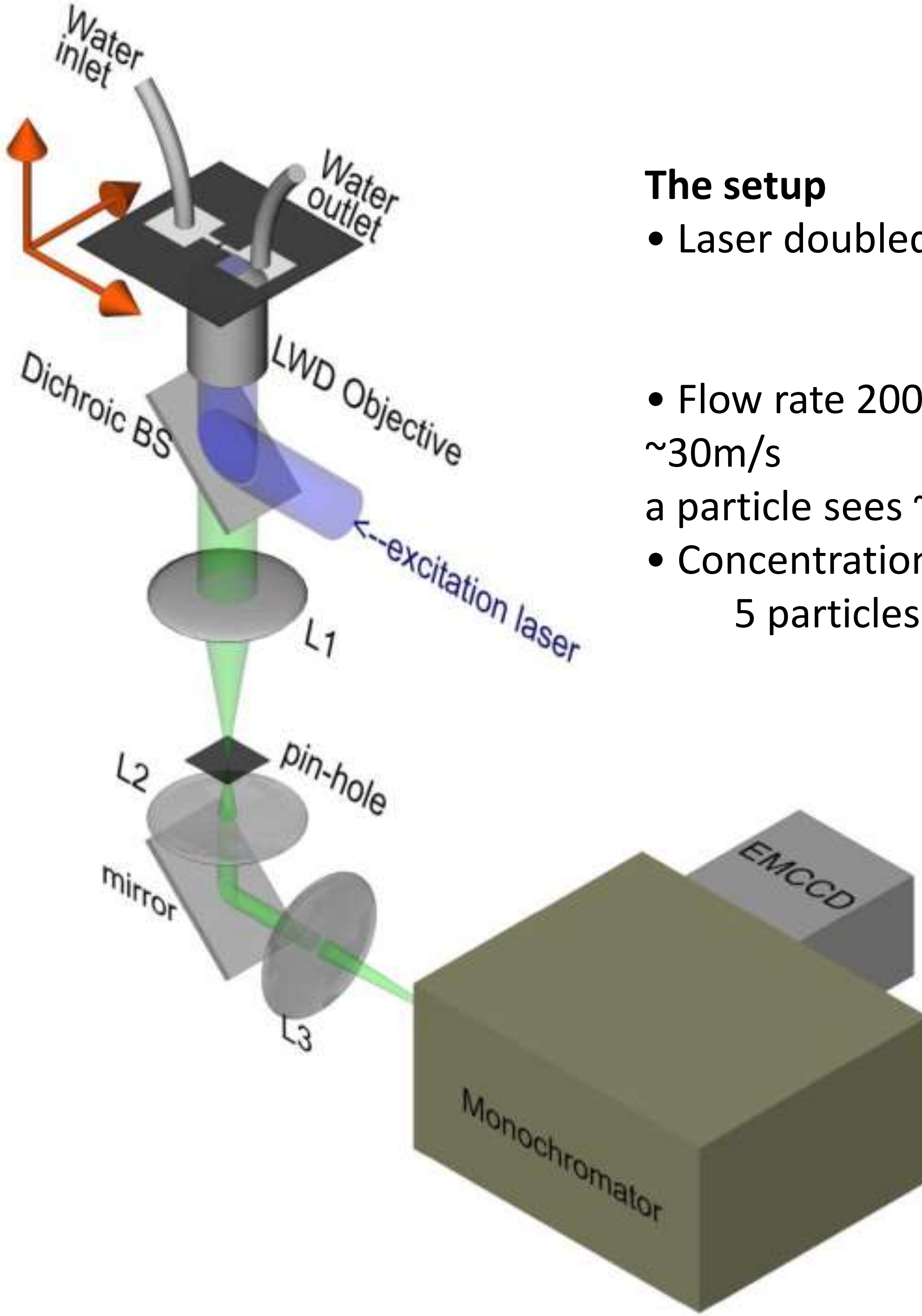
$St_2 = f_2 . L_{cav}/u_o =$ temps jet réentrant /période lachers bulles ($3\ 10^{-3}$ à $3\ 10^{-2}$)

1 mm

ΔP = 17 bars, U = 43 m/s



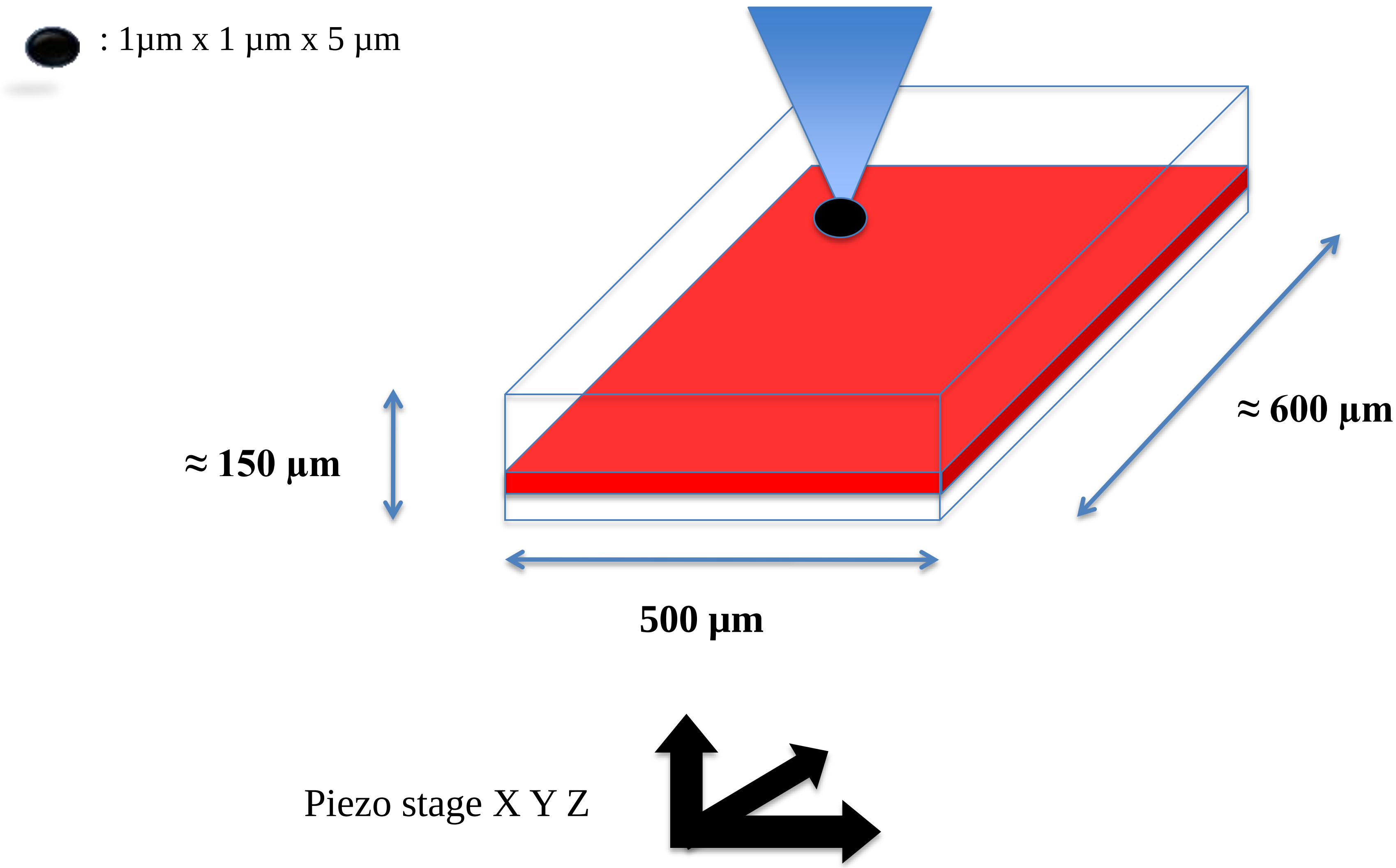
(durée réelle : 60 ms)

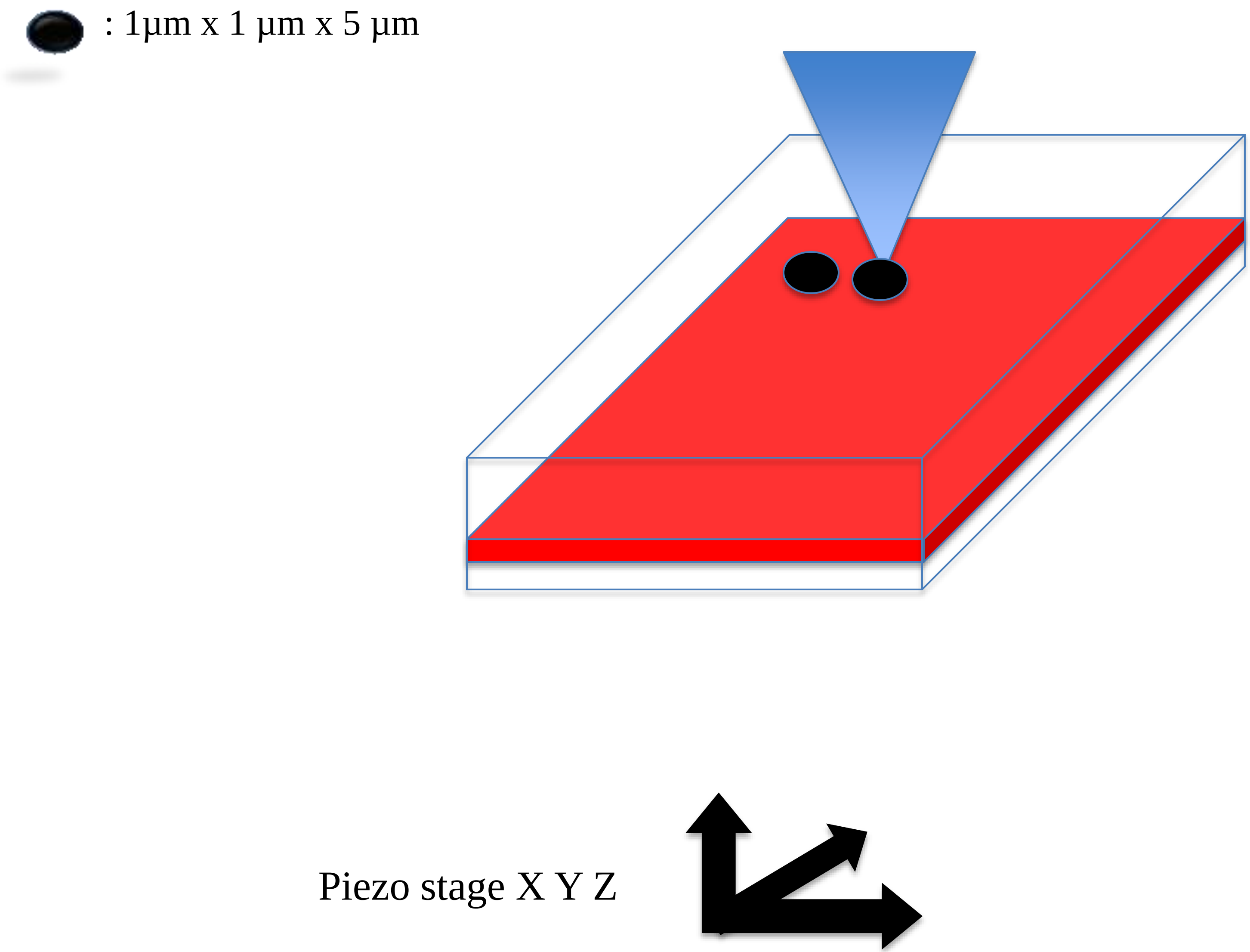


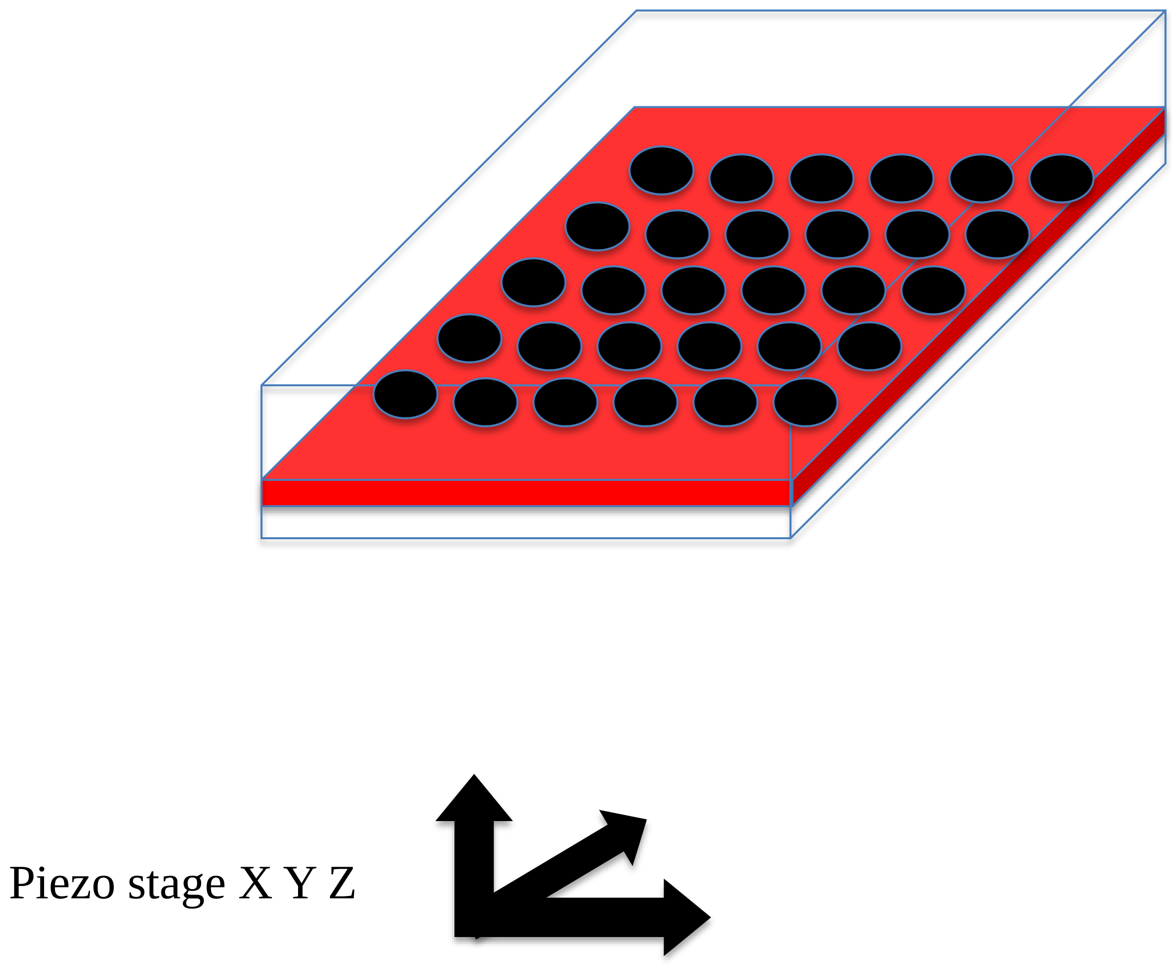
The setup

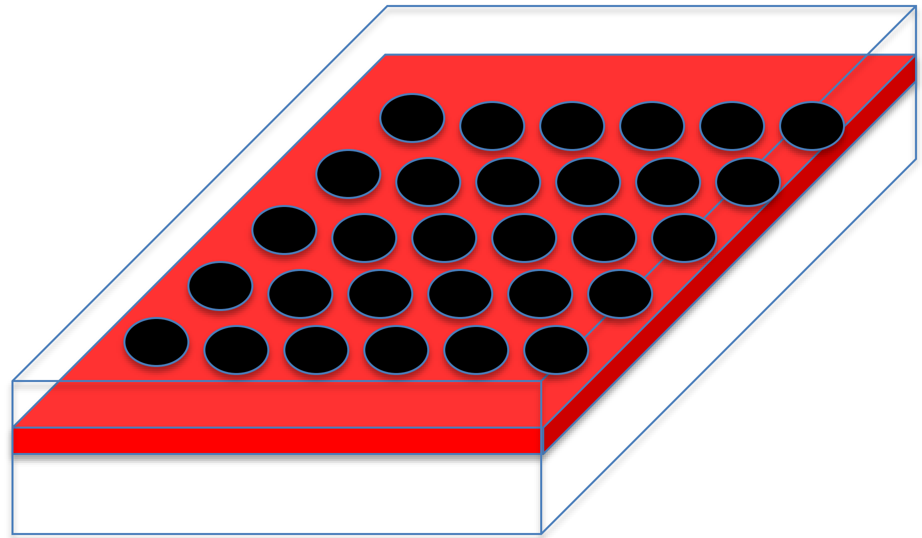
- Laser doubled fs TiSa 440nm 300fs
  80MHz
  30µW
- Flow rate 200-300µl/s speed of the water ~30m/s
  a particle sees ~2 laser pulses
- Concentration in particles 1g/l
  5 particles / voxel (2000FITC/voxel)

Cartographies thermiques

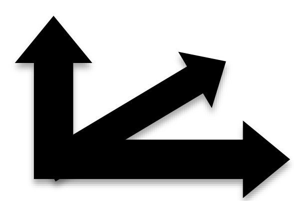


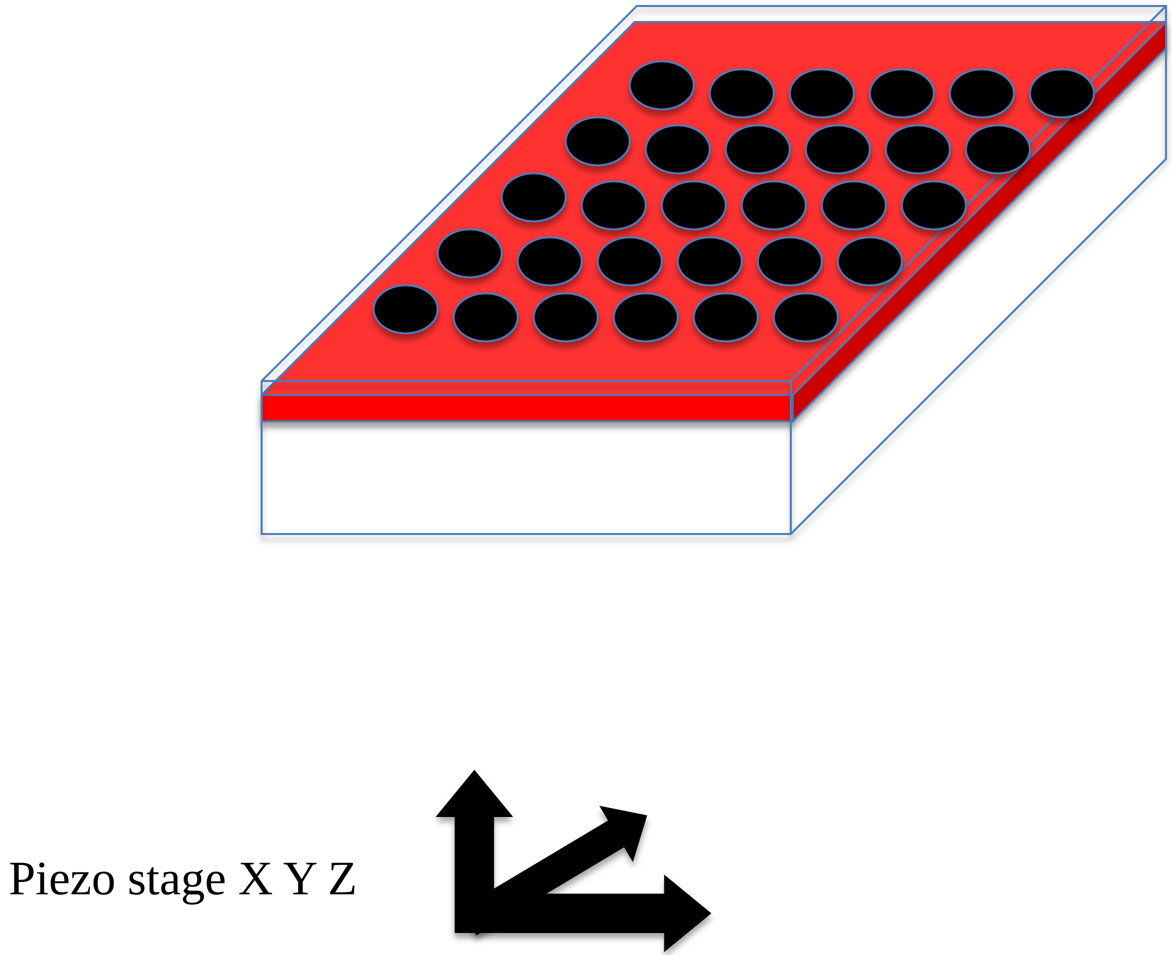

: 1µm x 1 µm x 5 µm
Piezo stage X Y Z


Piezo stage X Y Z



Piezo stage X Y Z




Piezo stage X Y Z

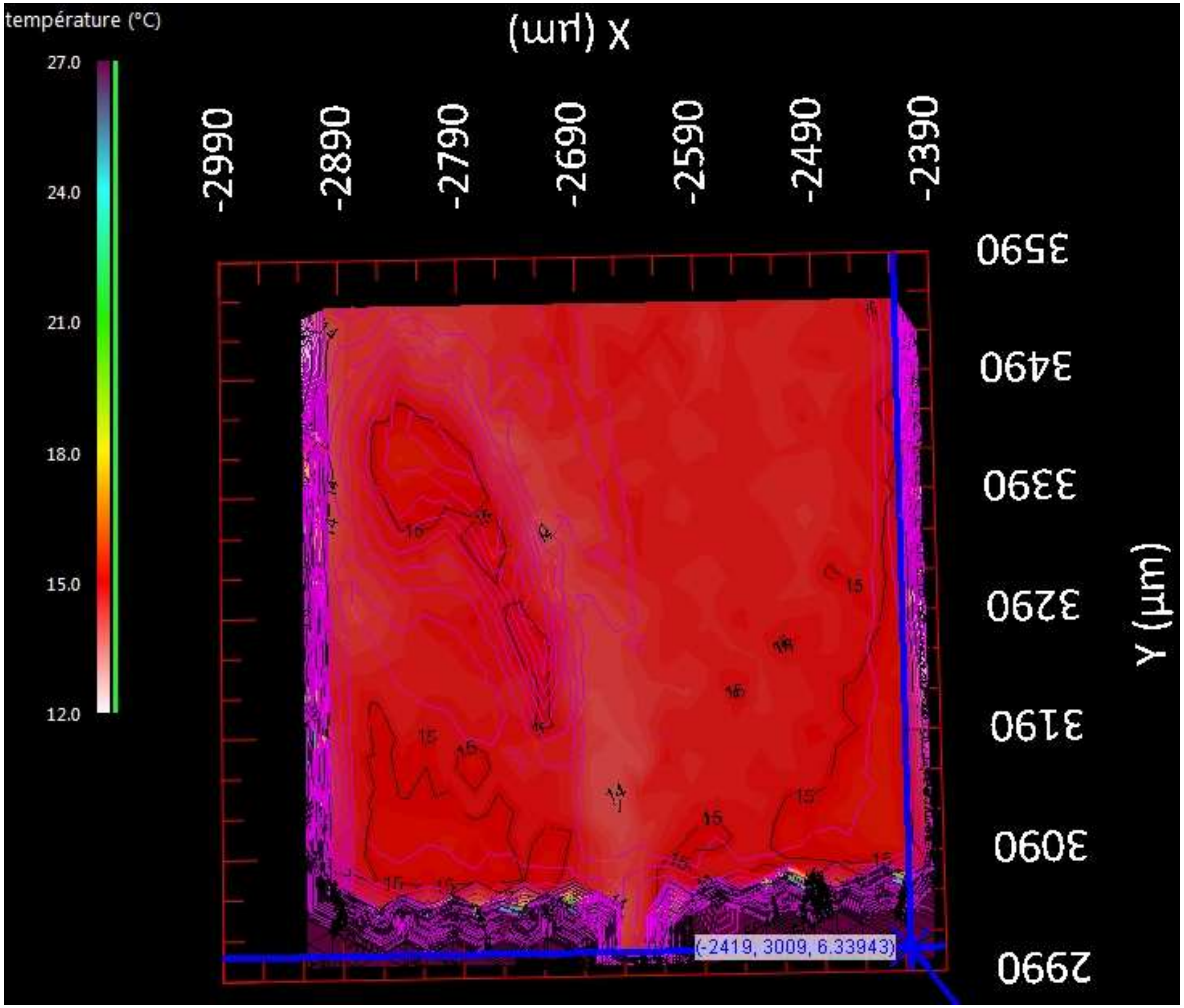
Thermal mapping

diaphragm downstream

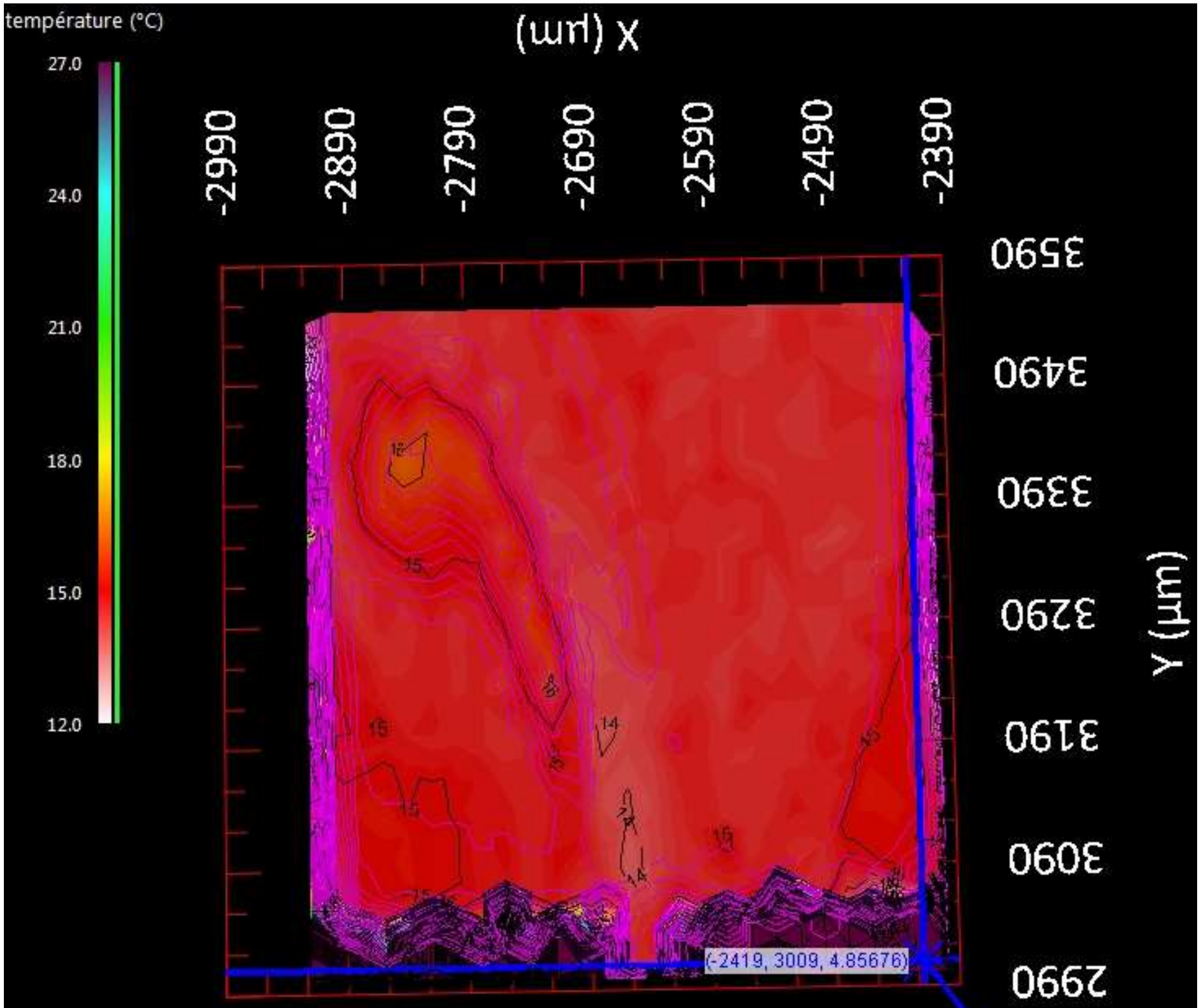
H=124µm flow rate = 217 µl/s (ΔP = 6.2 bars) two phase flow

0 < Z < H = 124 µm

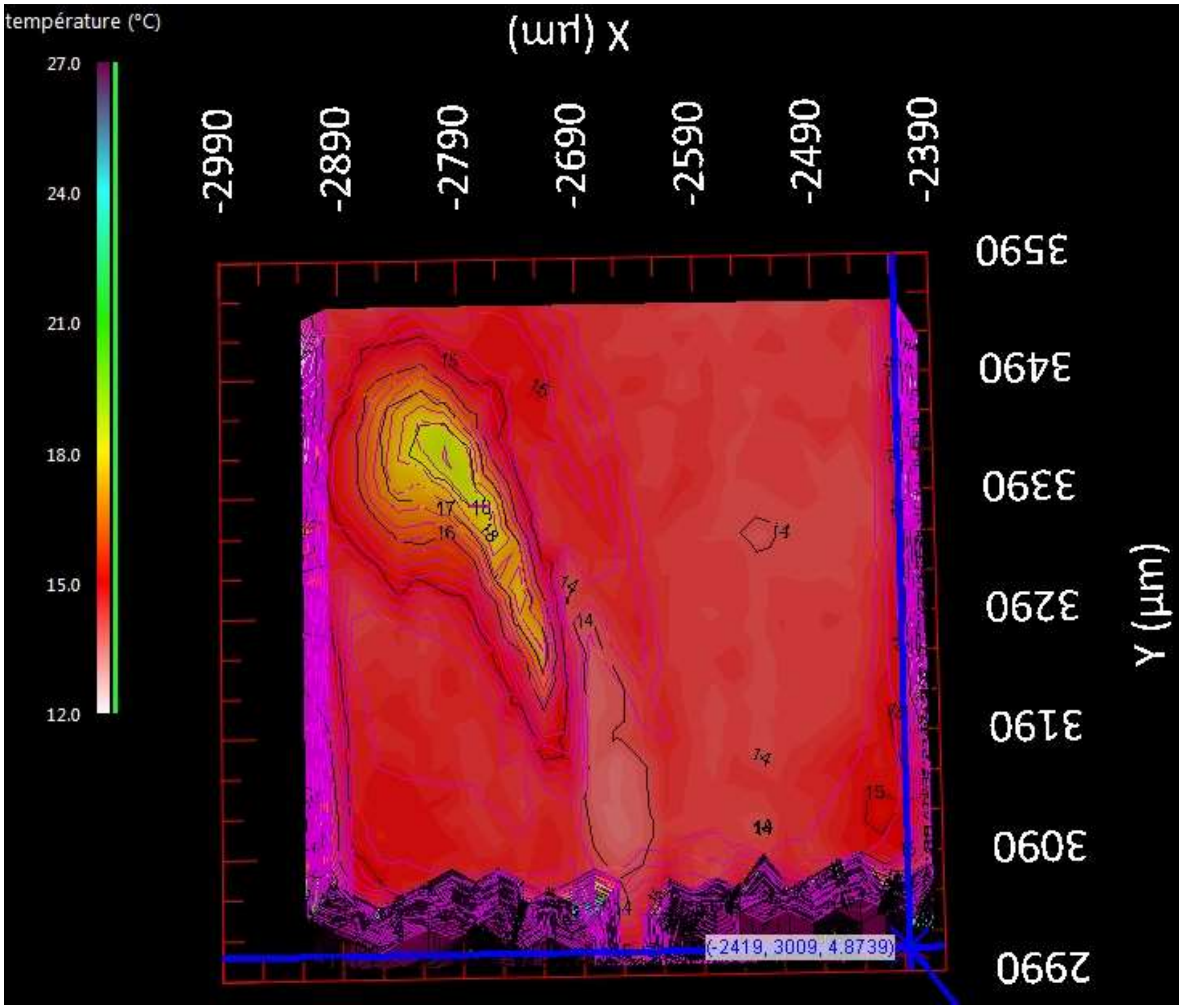
Z = 10 µm



Z = 36 µm

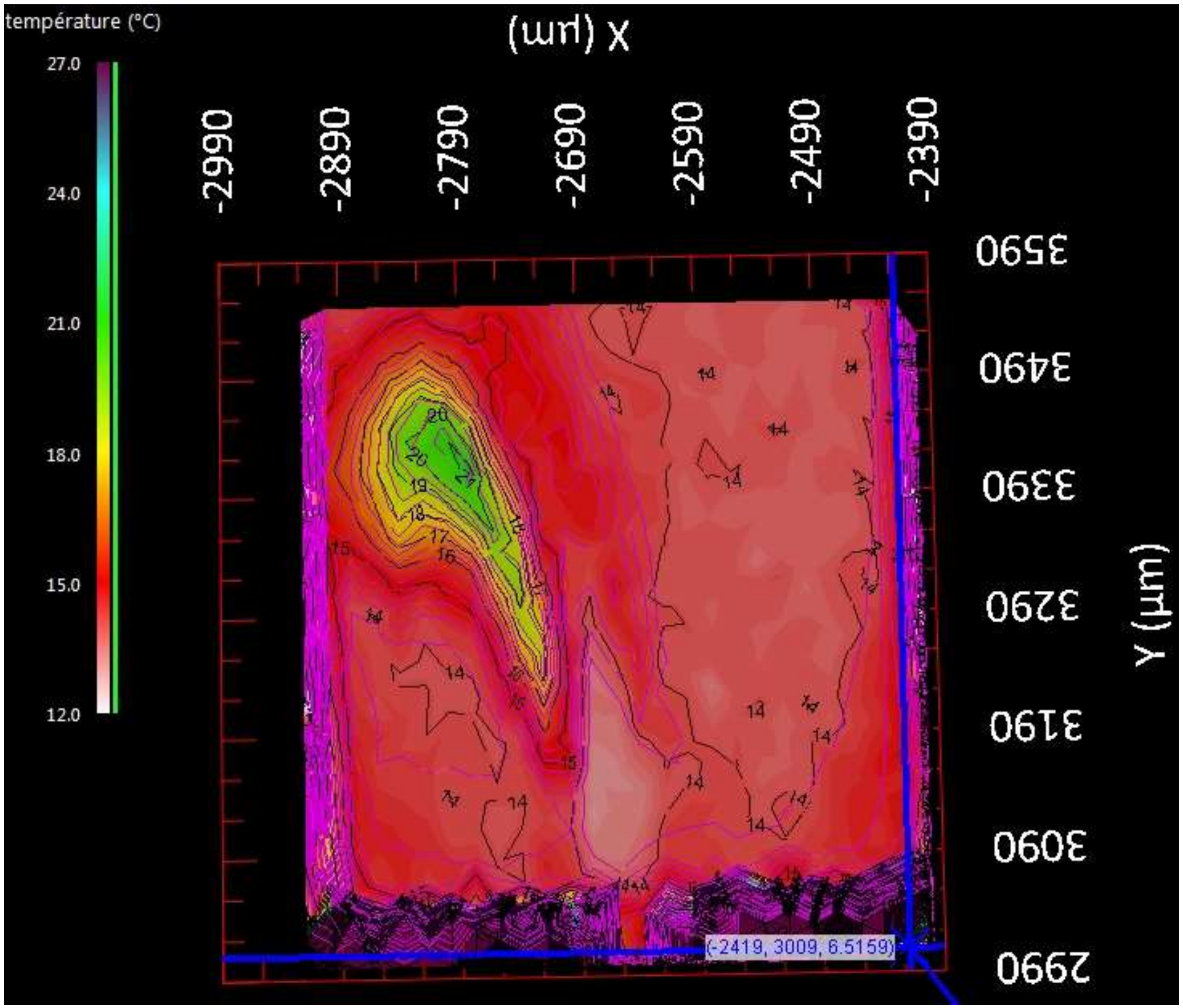

température (°C)
27.0
24.0
21.0
18.0
15.0
12.0
X (µm)
-2990
-2890
-2790
-2690
-2590
-2490
-2390
Y (µm)
3590
3490
3390
3290
3190
3090
2990
(-2419, 3009, 4.85676)

Z = 50 µm



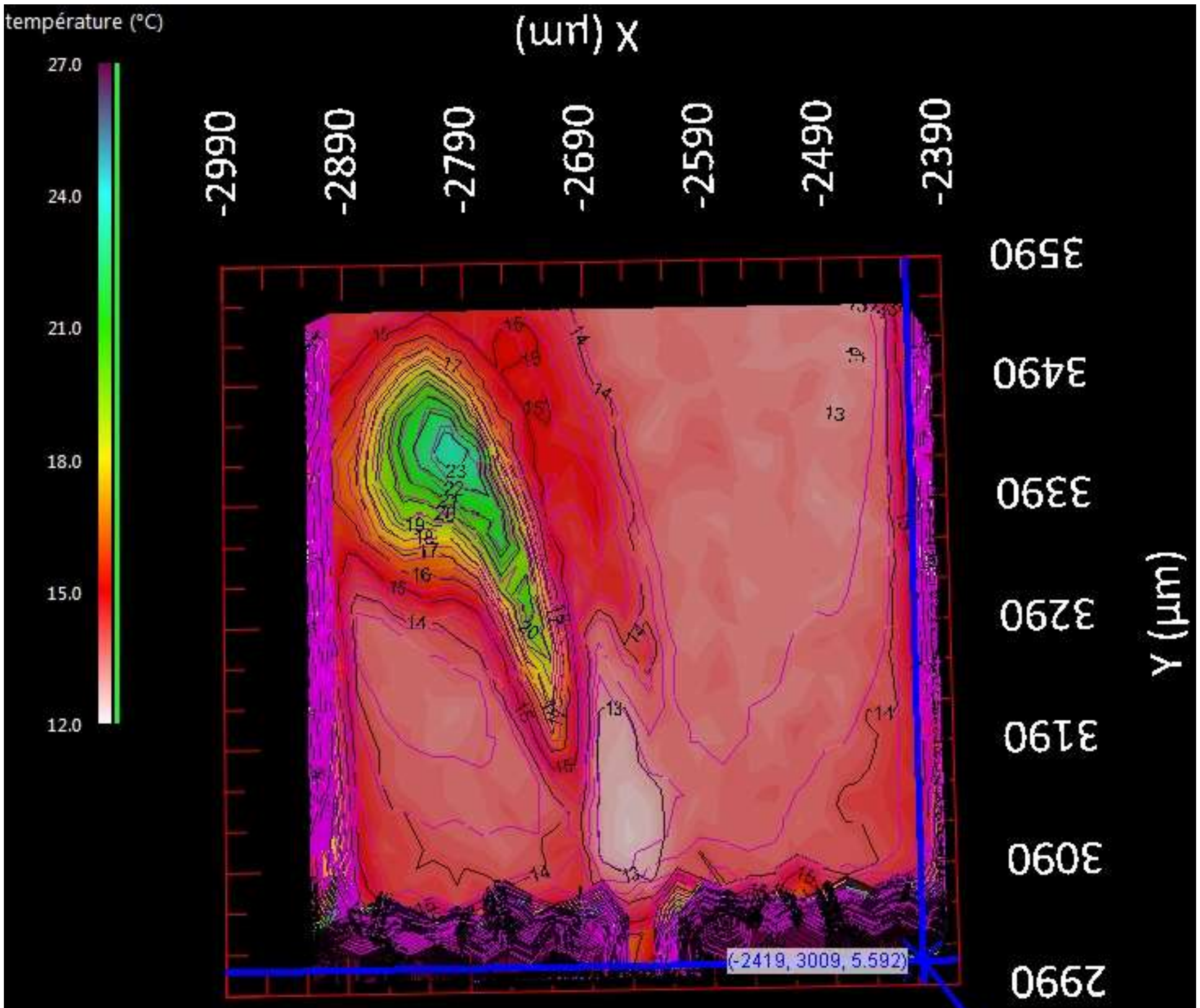
température (°C)
27.0
24.0
21.0
18.0
15.0
12.0
X (µm)
-2990
-2890
-2790
-2690
-2590
-2490
-2390
Y (µm)
3590
3490
3390
3290
3190
3090
2990
(-2419, 3009, 4.8739)

Z = 74 µm



température (°C)
27.0
24.0
21.0
18.0
15.0
12.0
X (µm)
-2990
-2890
-2790
-2690
-2590
-2490
-2390
Y (µm)
3590
3490
3390
3290
3190
3090
2990
(-2419, 3009, 6.5159)

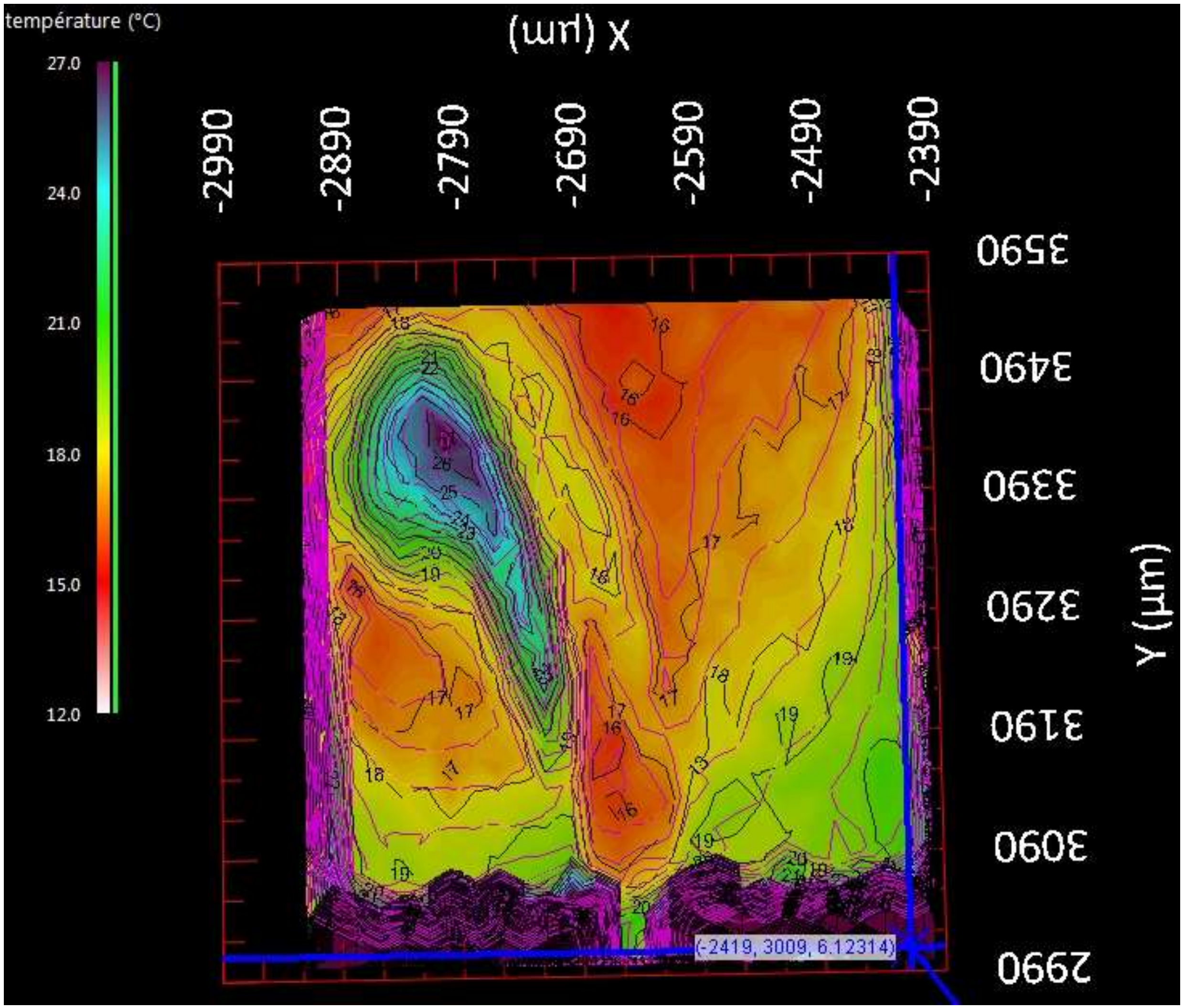
Z = 98 µm



température (°C)
27.0
24.0
21.0
18.0
15.0
12.0
X (µm)
-2990
-2890
-2790
-2690
-2590
-2490
-2390
3590
3490
3390
3290
3190
3090
2990
Y (µm)
(-2419, 3009, 5.592)

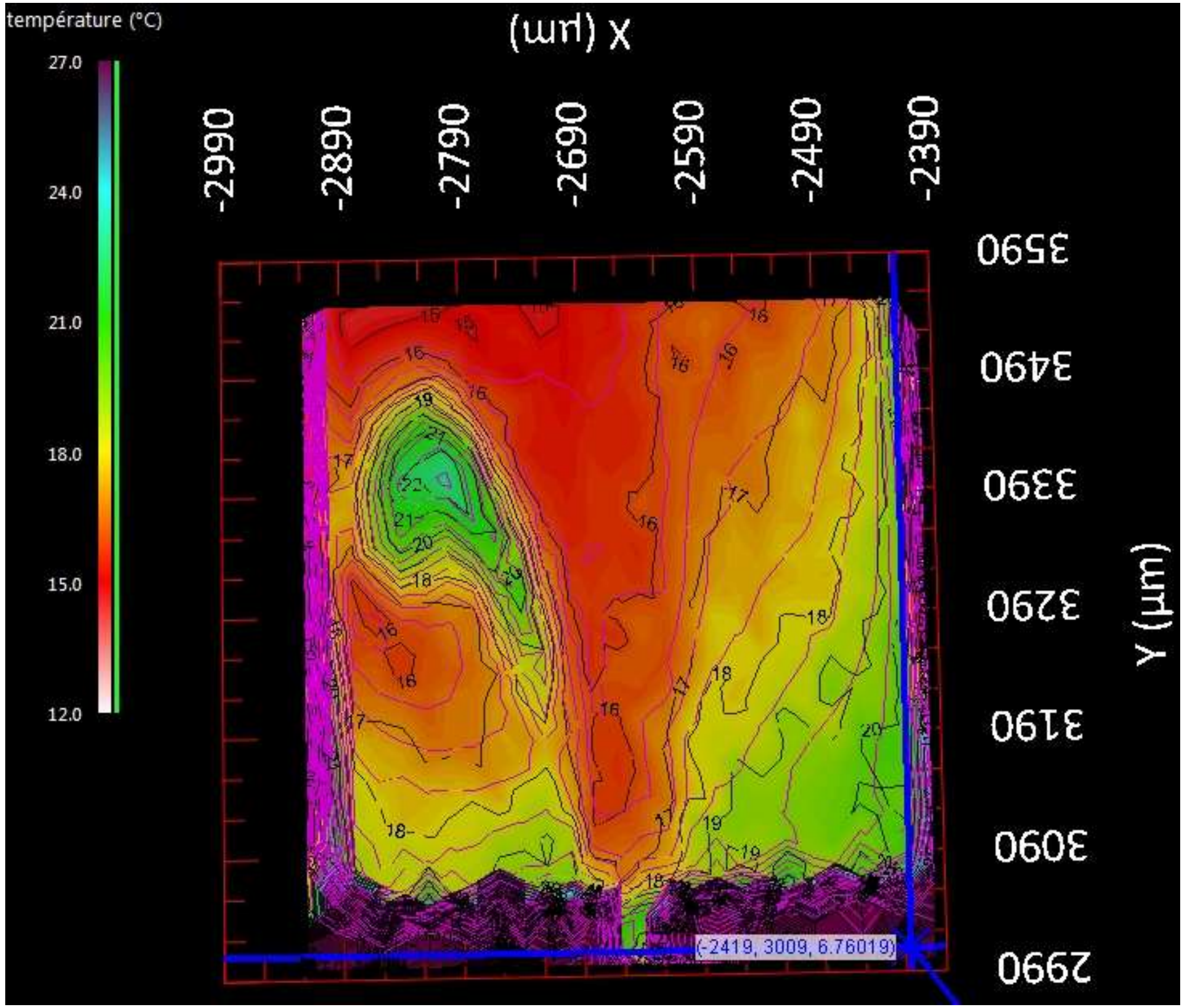
$\Delta P = 6.2$ bars

$Z = 114$ µm



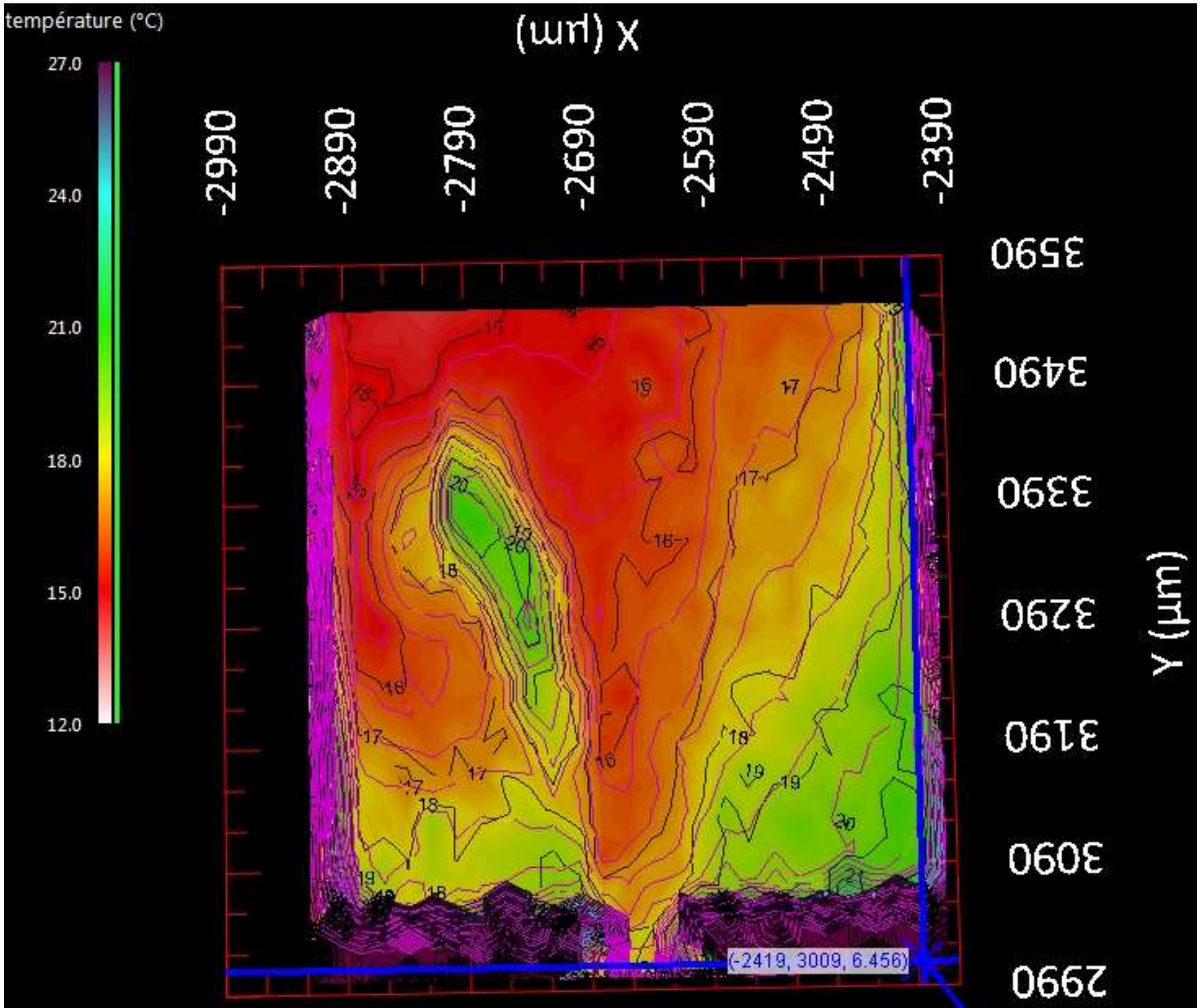
ΔP = 5.4 bars

Z = 114 µm



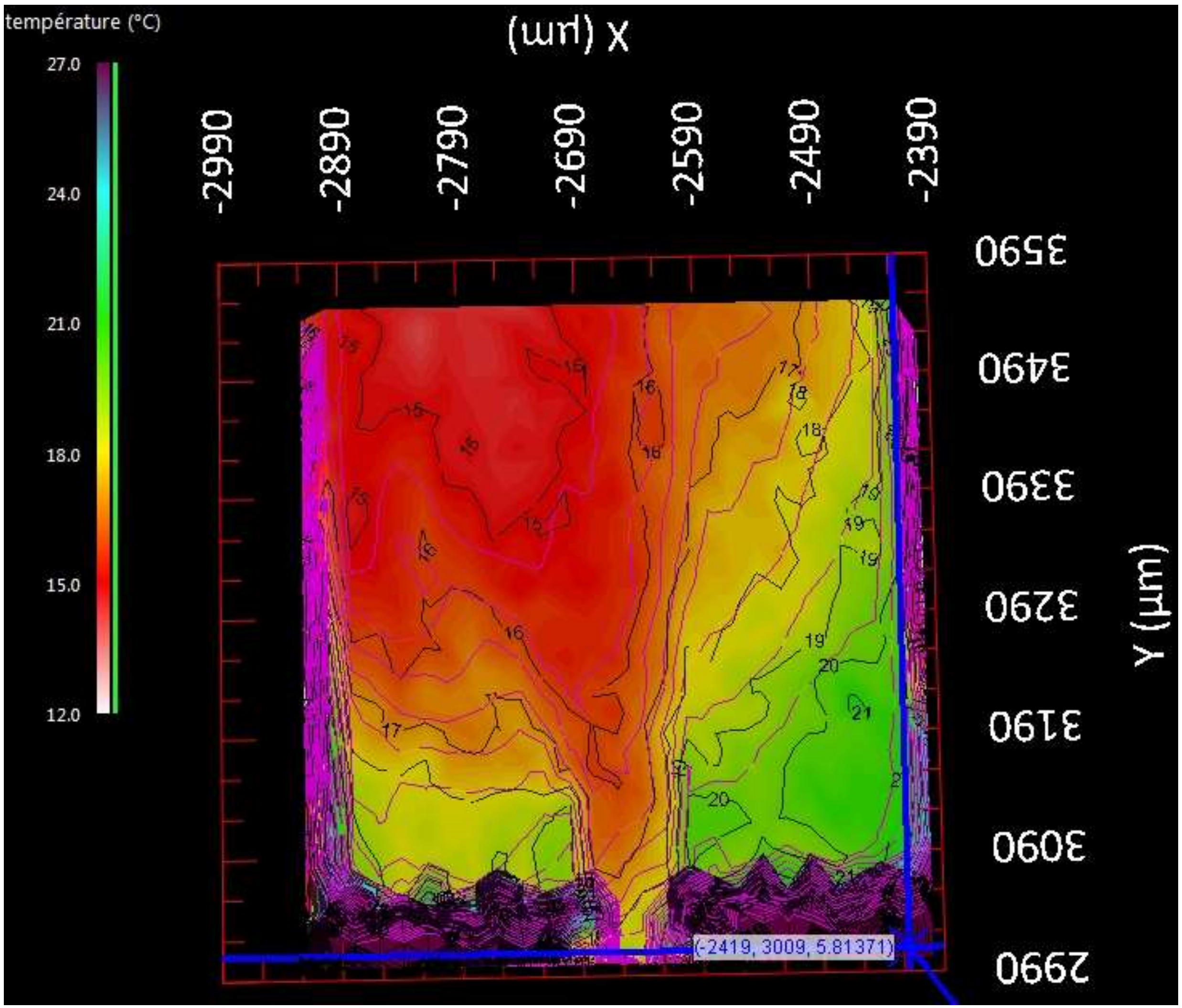
ΔP = 4.2bars

Z = 114 µm



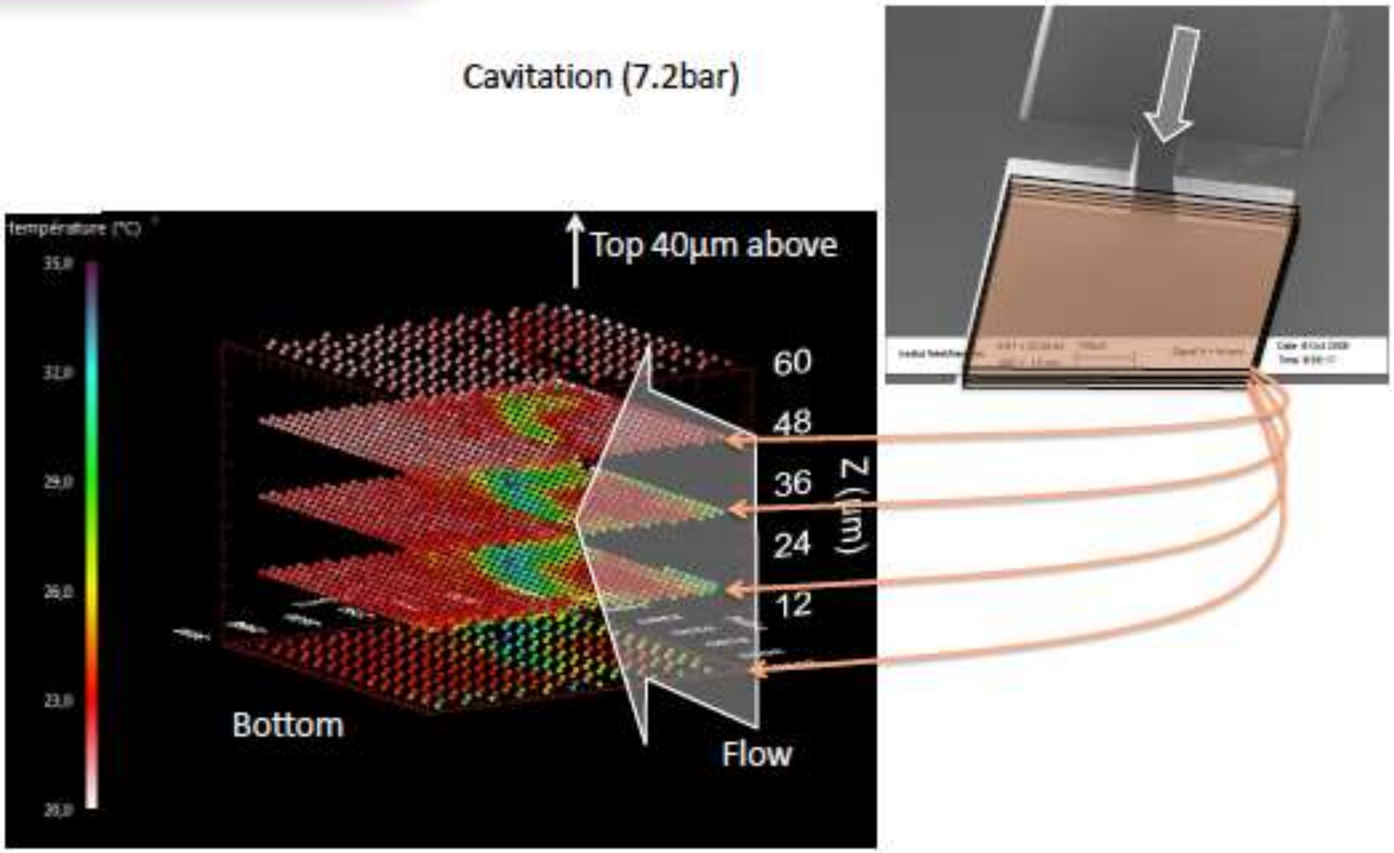
ΔP = 3.8 bars

Z = 114 µm



3D distribution

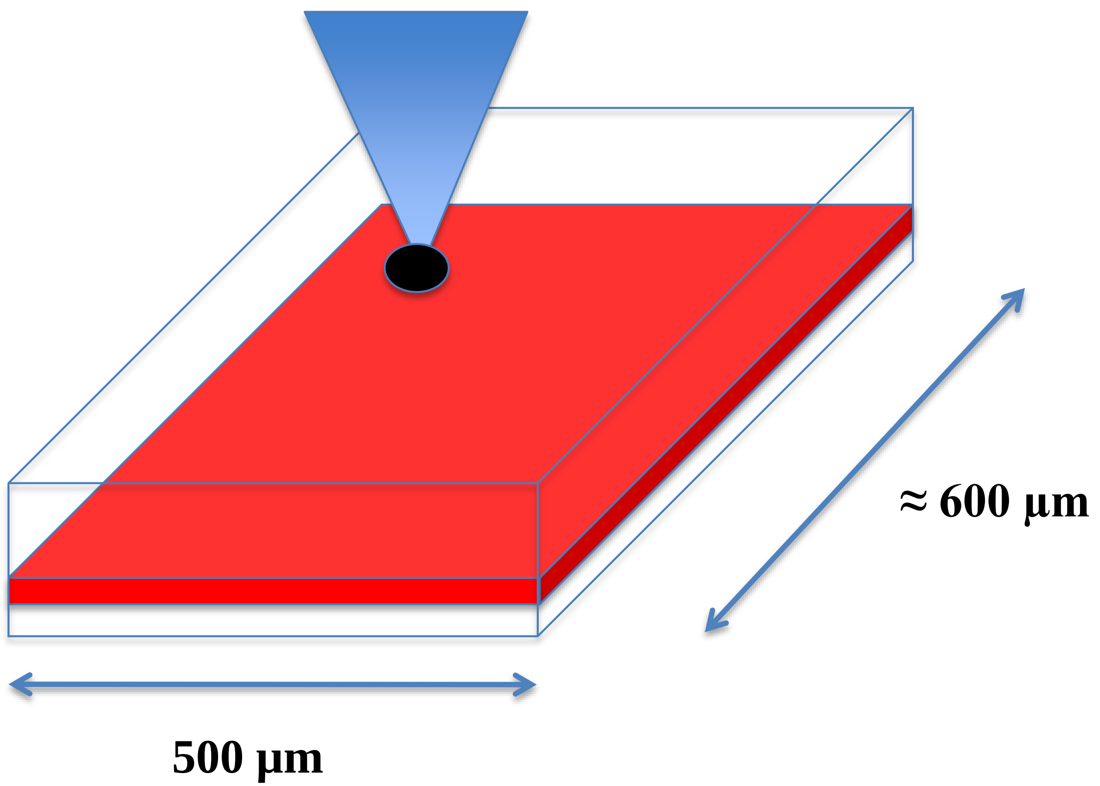
Cavitation (7.2bar)



F. Ayela et al., *Physical Review E*, 88, 043016 (2013)

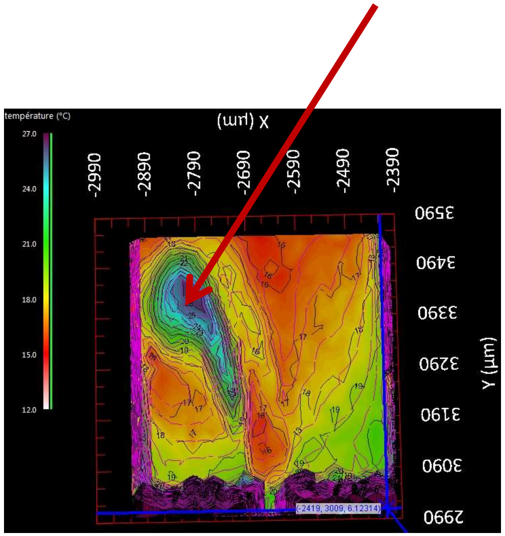
Thermal gradient < - > cavitation ?

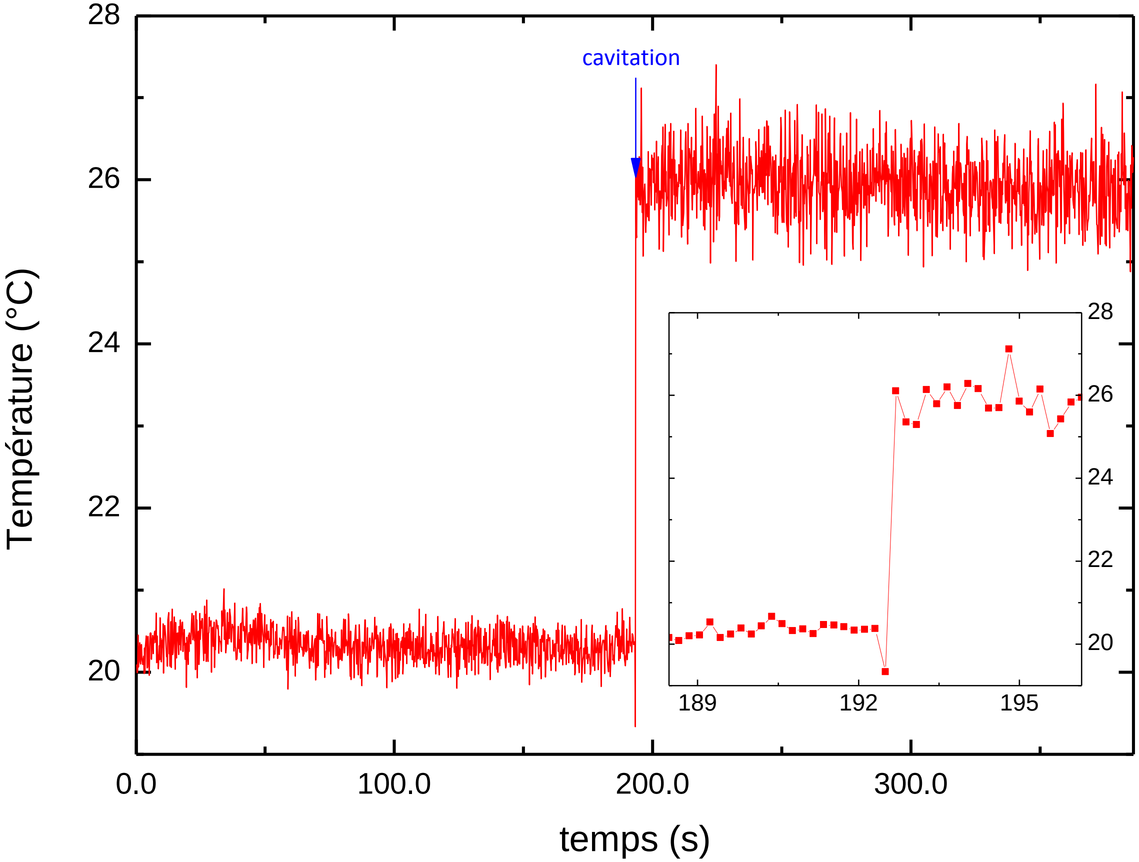
Real time local observation
Spot focused where ΔT_{max} formerly observed
Starting from a single liquid metastable flow
Wait and see ....

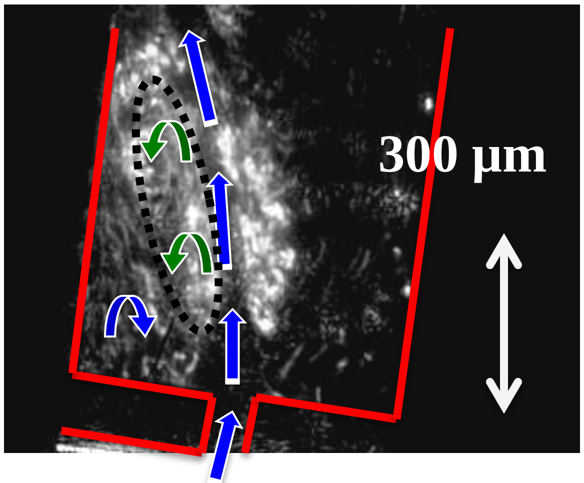


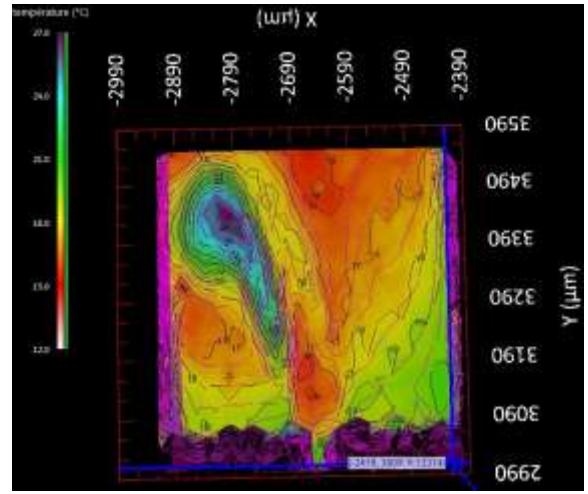
Thermal gradient < - > cavitation ?

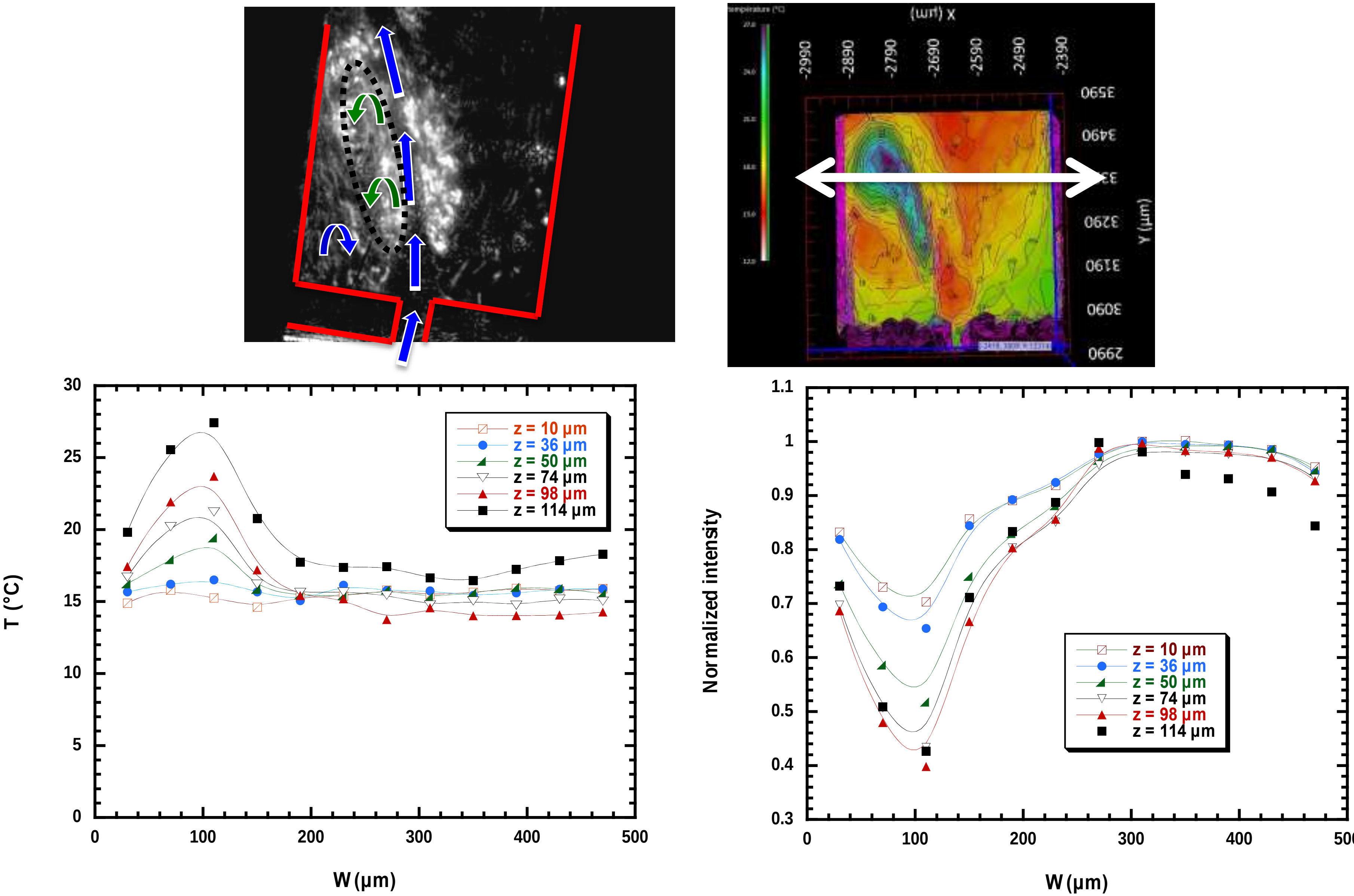
ΔP = 6.2bar, voxel under investigation






300 µm


X (µm)
-2990
-2890
-2790
-2690
-2590
-2490
-2390
Y (µm)
3590
3490
3390
3290
3190
3090
2990



T (°C)
W (µm)
z = 10 µm
z = 36 µm
z = 50 µm
z = 74 µm
z = 98 µm
z = 114 µm
Normalized intensity
W (µm)
z = 10 µm
z = 36 µm
z = 50 µm
z = 74 µm
z = 98 µm
z = 114 µm

Cartographies thermiques

Manips en cours : **mesures par effet Raman (< 0)**

cartographies thermiques sur µ -diaphragmes 'longs'

µ - venturis

µ - marche

Cavitation 'exotique'

butanol, isopropanol, diethyl ether, mélanges binaires ….

eau + µ système fluidique : transition à Re ≈ 2000

Dans quelle(s) condition(s) : cavitation à Re < 2000 (écoulement laminaire) ?

Condition $P_{min} < P_{sat}$: $D_h < \mu_l.Re/(2\rho_l P_{atm})^{1/2}$

eau : D_h < 140 µm
butanol : D_h < 630 µm
ether : D_h < 54 µm

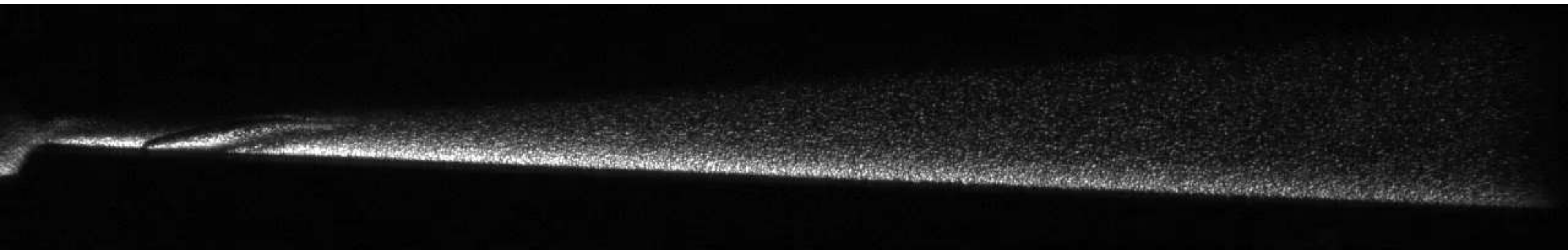
Effets thermodynamiques

	$\Delta T^{\bullet}$ (K)
eau	0,01
N2 liquide	0,6
diethyl ether	0,70
ethanol	0,90
isopropanol	0,94
butanol	1,12

Cavitation 'exotique'

durée réelle d'enregistrement : 4 ms
130000 images / sec

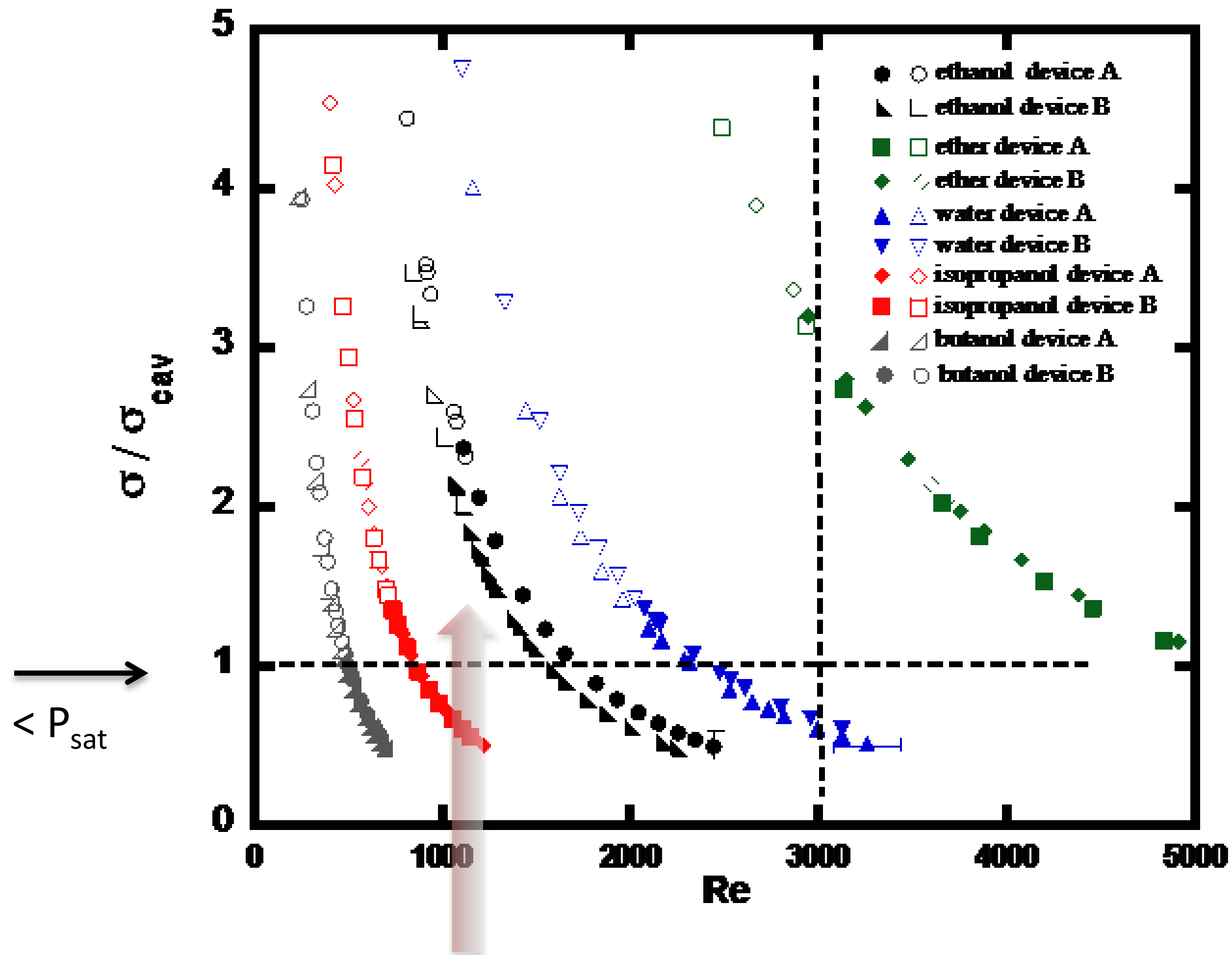
butanol - Re = 400



diethyl ether pur - Re = 5000

Cavitation 'exotique'

tests : 2 µ diaphragmes



vides : monophasique

pleins : diphasique

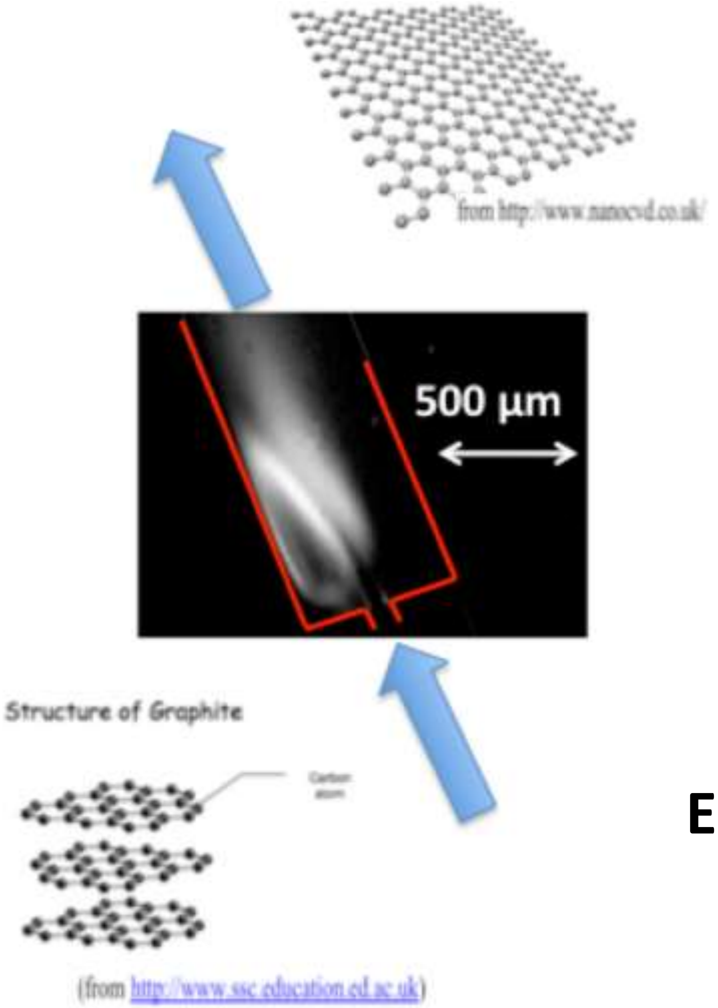
le mystère de l'éthanol : transition -> cavitation précoce

déjà observée par Péles (2005) :

tension surface éthanol < celle de l'eau

mais tension surface butanol , isopropanol ≈ celle de l'éthanol ….

Délamination assistée par cavitation / puce



$W/S_{(laminaire)} \approx \mu L U_m / H$

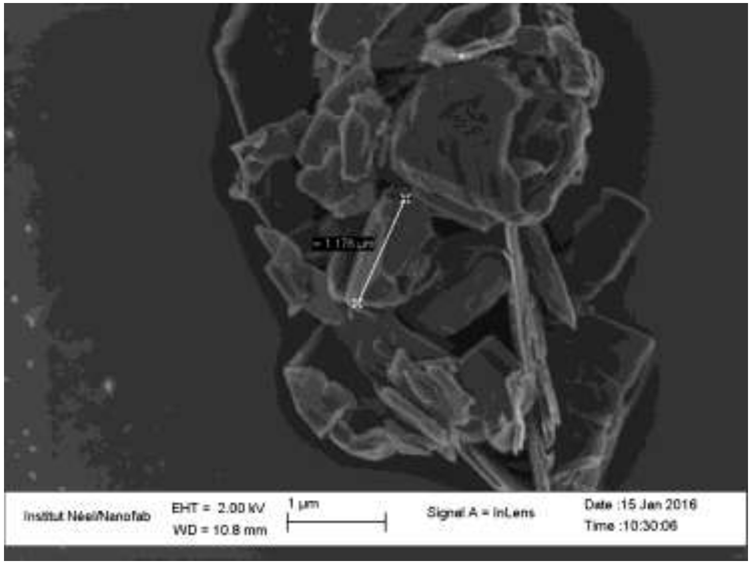
$\approx 1 J/m^2$

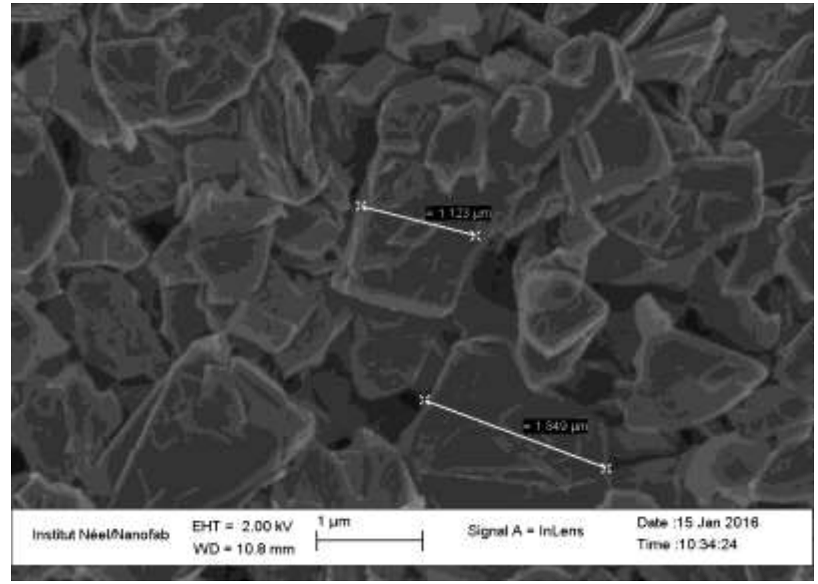
(µsystème)

$E_{liaison}$ 2 plans : ≈ 10 kJ /mole

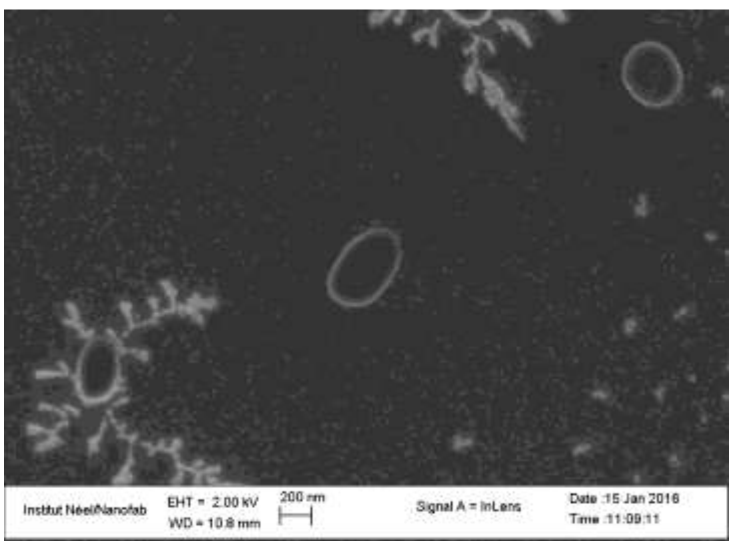
Délamination assistée par cavitation / puce

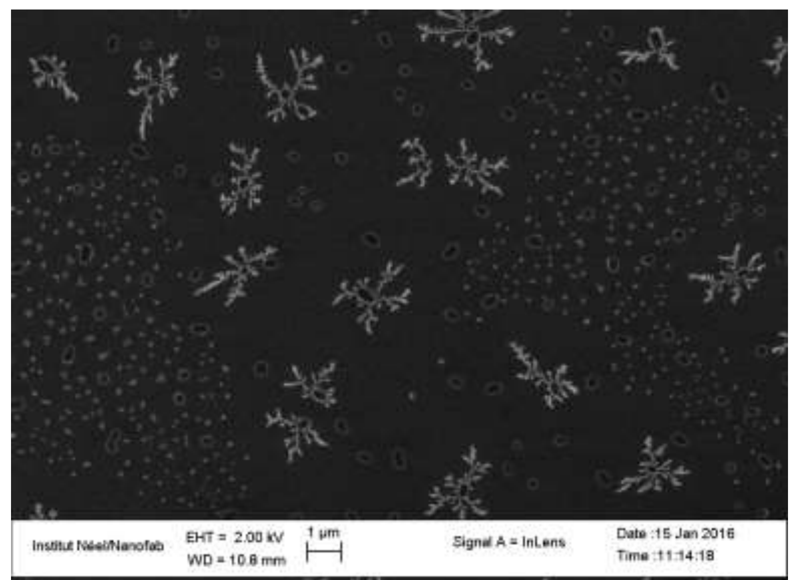
1 g de graphite + 600 ml H2O + 3 gouttes surfactant





6 passages ‘cavitants’ à ΔP = 10 bars



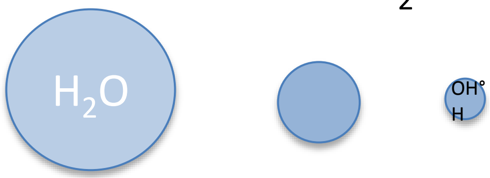


Orientations futures

Génie des procédés

sonochimie

H_2O -> OH° + H



-> cavitation luminol (+ OH° -> hν)

sonoluminescence

diffusion gaz rare
+
T ≈ 10000 K

démontré en cavitation acoustique (plusieurs cycles, bulle sphérique -> SL
bulle asphérique -> SC

peu d'infos en cavitation hydrodynamique – pas de modèle clair

1ers essais en 'cavitation hydro sur puce' : RAS cavitation fluides cryogéniques

Projet SBT – LEGI

-> effets thermodynamiques avec N2 liquide

+CNES

Objectif 2016 :
connectique hydro - cryogénique
alimenter microsystème en N_2 liquide
démontrer cavitation hydrodynamique