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Experimental and Numerical Investigation of Two Phase Flow in a Model of Nanoporous Medium

LowPerm 2015

Les rencontres scientifiques d'IFP Energies Nouvelles

Antoine Naillon^{1,2} – Philippe Lefort¹ – Sandrine Geoffroy³ – Marc Prat¹ – Pierre Joseph²

(¹ : IMFT, ² : LAAS, ³ : LMDC)

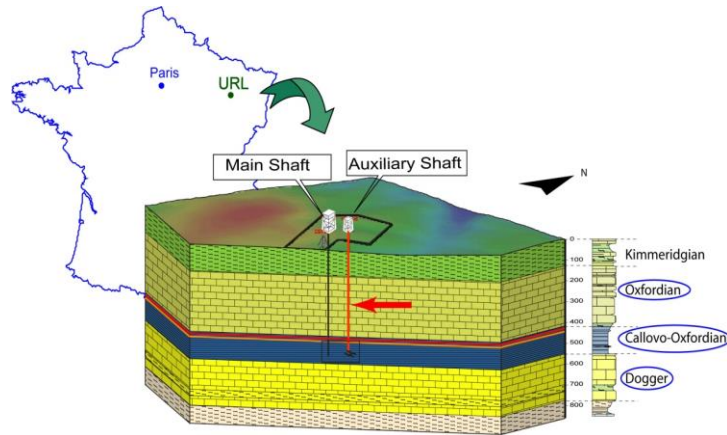
1. Motivation / Context

2. Fabrication and procedure

3. Two phase flow in dead end nanochannels

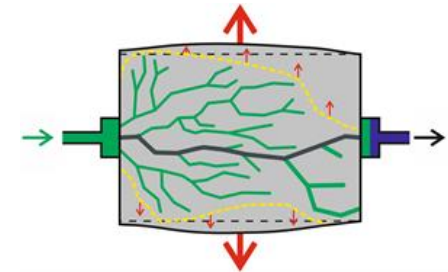
Conclusion

Repository Issue of Long Life Radioactive Wastes



ANDRA's project of repository of long life radioactive wastes

- Specificities of this deep repository:
 - **Gas generation** (mainly H₂ from corrosion of metallic component)

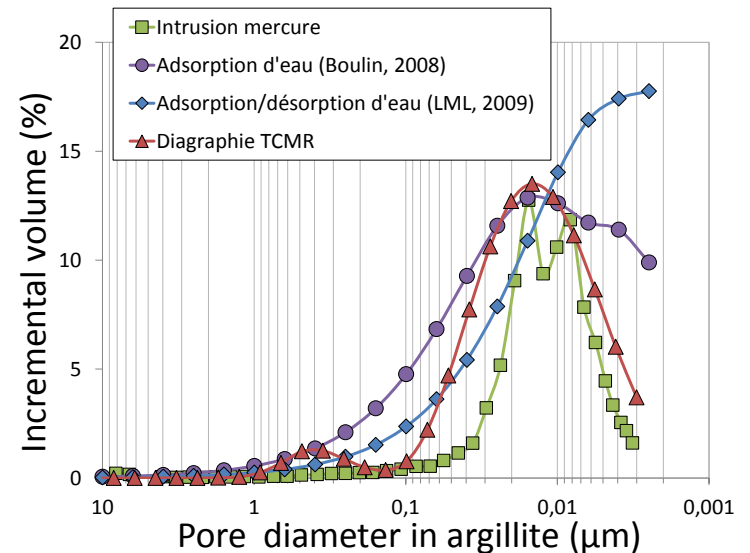


Drainage experiment of BGS

- Typical pore size : **few tens of nanometre**

- Issues:

- Influence of gas generation on fluid flow around repository galleries?



JC Robinet - ANDRA

Goals : specificities due to nanometer scale

- **Validation of hydraulic law**
 - Kinetics of imbibition

- **Effect of high capillary pressure**
 - Flow and mechanical deformation



$$P_c = \frac{2\gamma}{a} = 72 \text{ bar}$$

$$a = 20 \text{ nm}, \gamma = 72 \text{ mN/m (water)}$$

- **Modification of physical properties:**
 - Dissolution properties
 - Cavitation
 - Rarefied gas

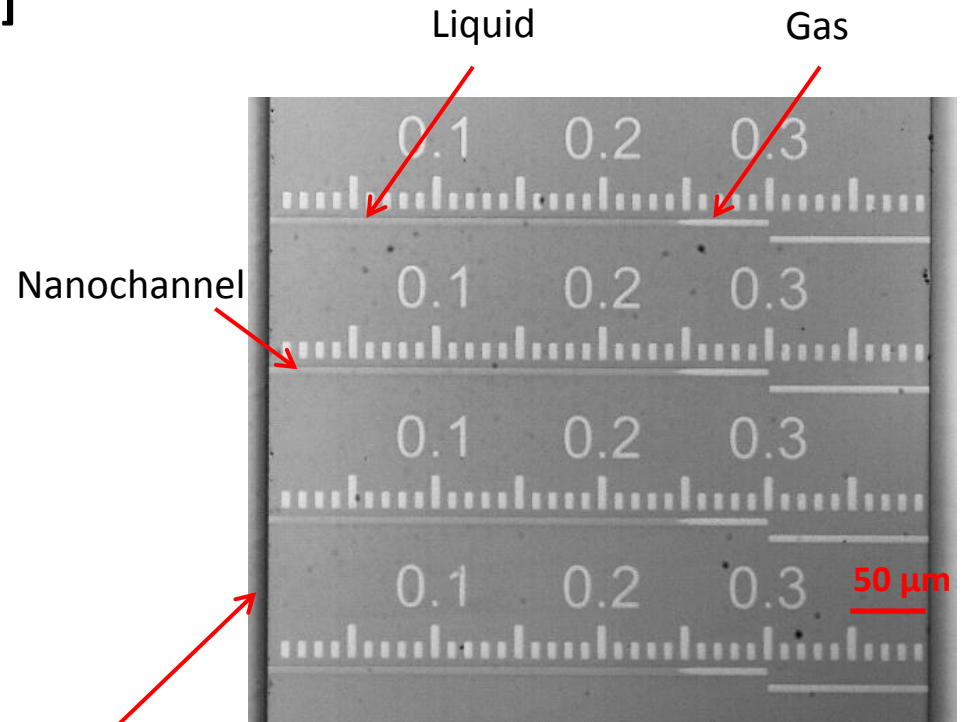
Our approach : Nano-fabrication

- **Classical use of model system: [1]**

- Controlled geometry
- Phase visualisation
- Parallelization of experiments
- High reproducibility

- **Emergence of nanofluidics**

< 200 nm [2]



*Picture of two phase flow in dead end nano channel
(depth = 54 nm)*

[1] P. Lenormand et al., *J. Fluid Mech.* (1988)

[2] C. Duan et al., *Biomicrofluidics* (2013)

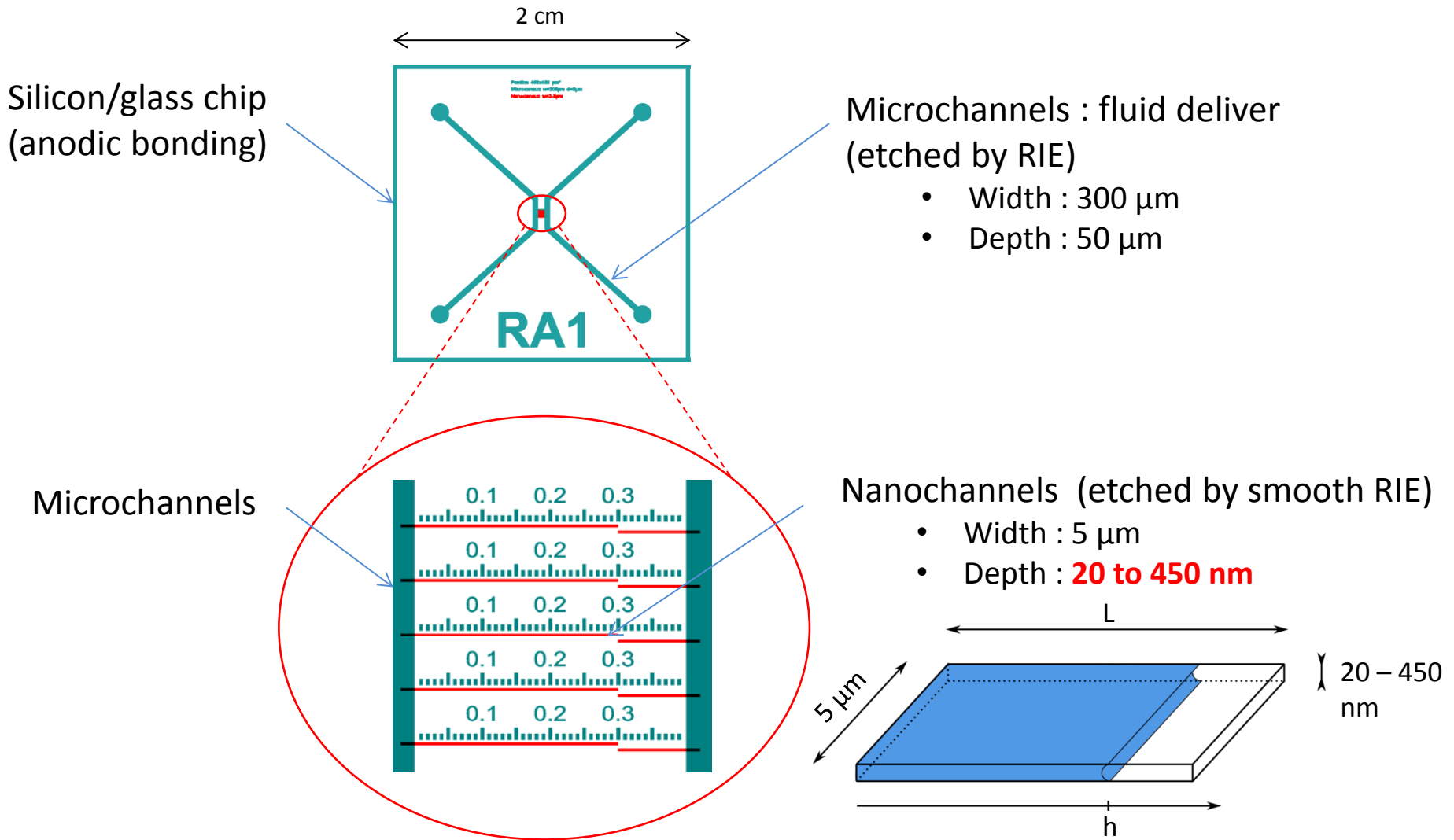
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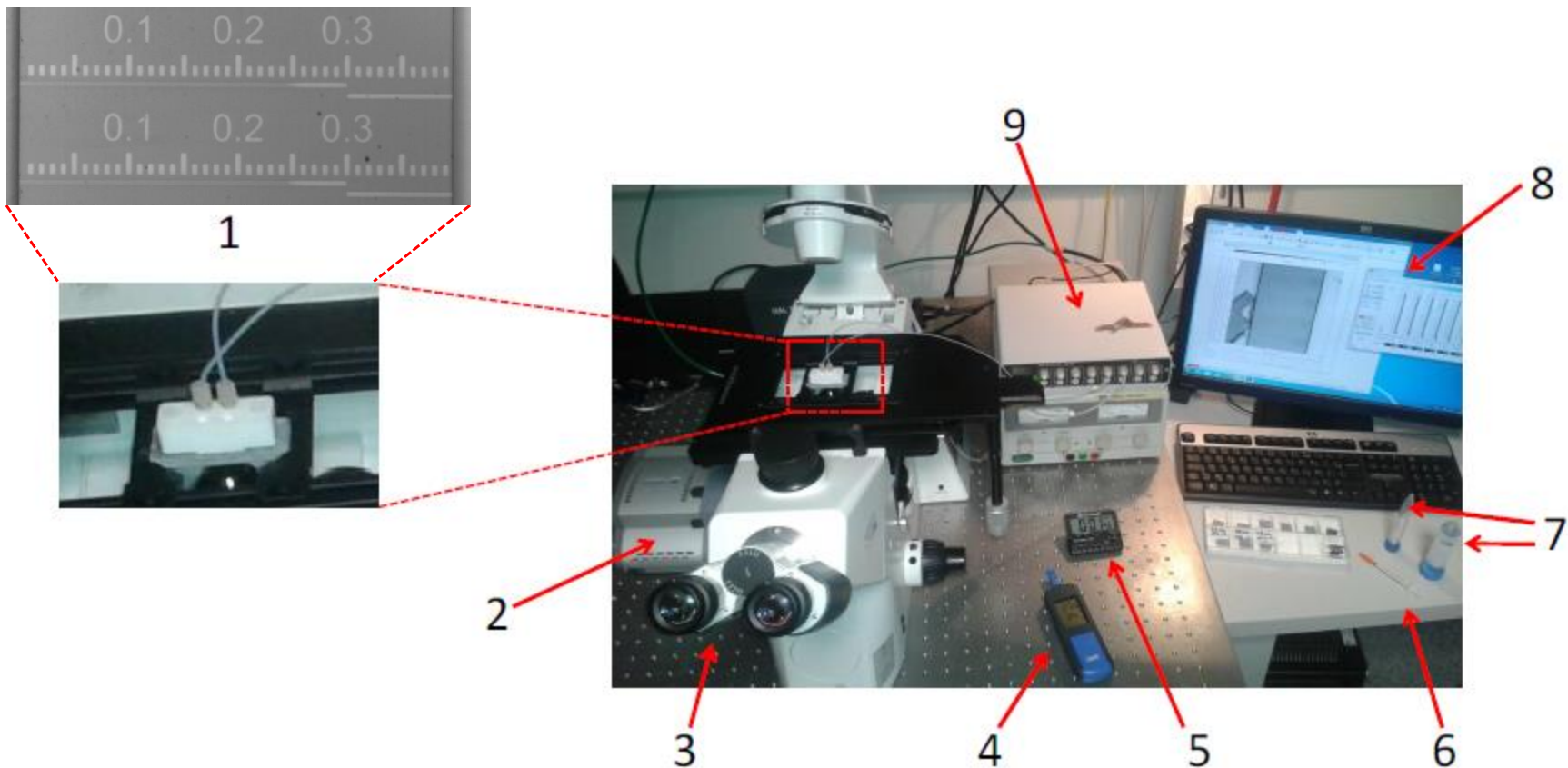
3. Two phase flow in dead end nanochannels

Conclusion

Nano-fabricated chip



Experimental Procedure



- 1. Experimental support
- 2. Video camera
- 3. Inversed microscopy

- 4. Thermo and moisture meter
- 5. Chronometer
- 6. Needle

- 7. Sample
- 8. Control screen
- 9. Pressure deliver

1. Motivation / Context

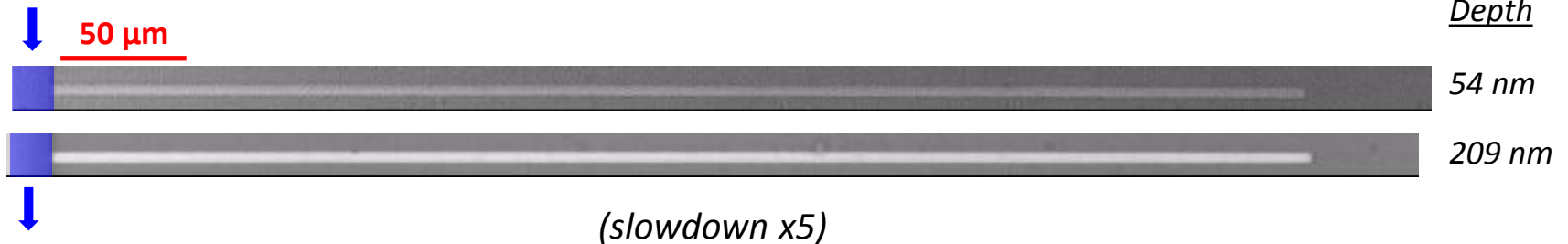
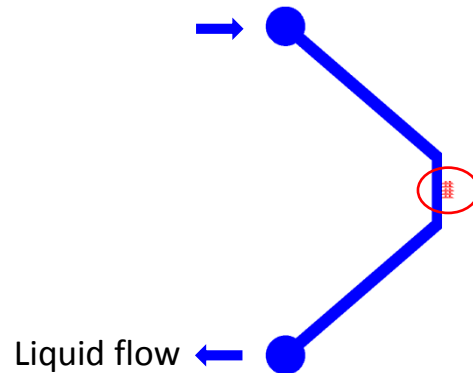
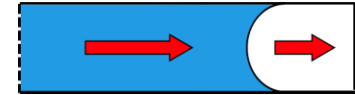
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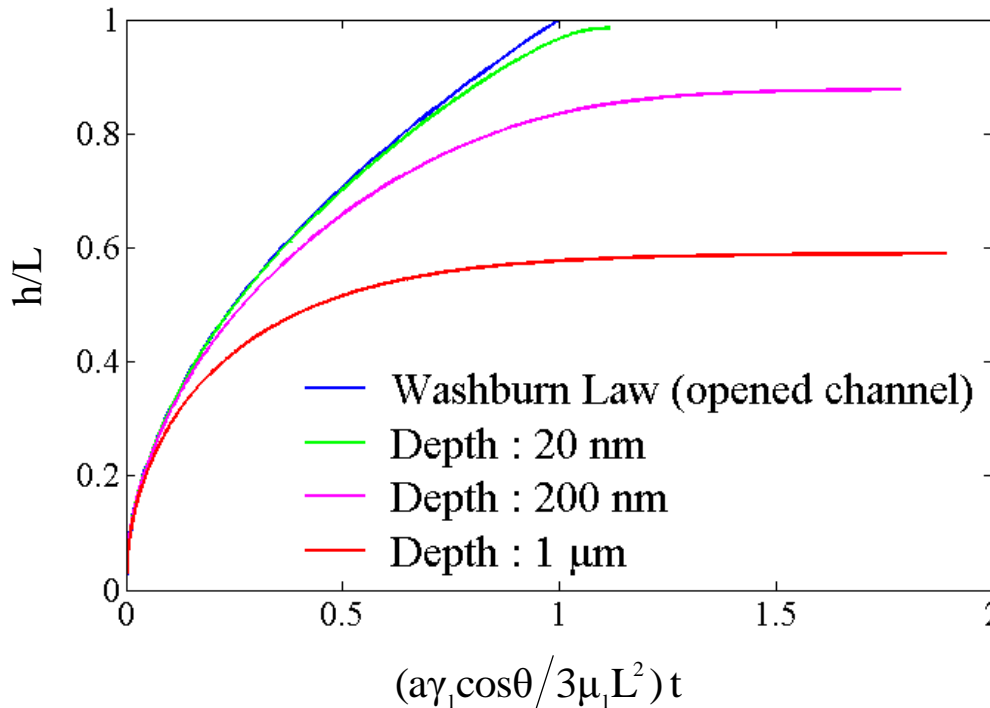
Imbibition in dead end nanochannels

- **Beginning of imbibition** => gas pressurization



=> Meniscus dynamics is less affected at nanometer scale by gas pressurization effect

Imbibition in dead end nanochannels



h : meniscus position

a : channel depth

L : channel length

γ_l : surface tension

μ_l : liquid viscosity

Θ : contact angle

$$\alpha = \frac{p_0}{p_{\text{cap}}}$$

Washburn law:

$$h = \sqrt{\frac{a\gamma_l \cos\theta}{3\mu_l}} t$$

Imbibition in dead end channel : (with gas compression) [1]

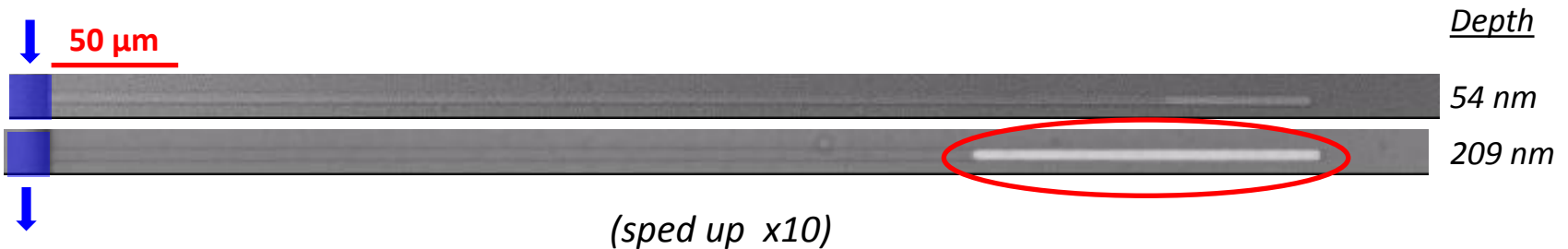
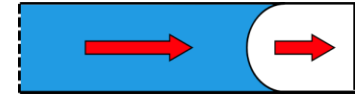
$$t(h) = \frac{h^2}{2(1+\alpha)} - \frac{\alpha h}{(1+\alpha)^2} - \frac{\alpha}{(1+\alpha)^3} \ln[1 - (1+\alpha)h]$$

=> Gas compression has low influence on filling kinetics for the smallest depth

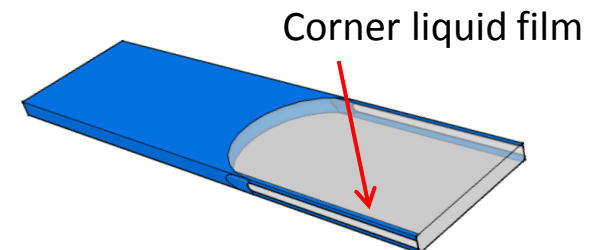
[1] V.N. Phan et al., *Langmuir*, 2010

Imbibition in dead end nanochannels

- End of imbibition => gas dissolution

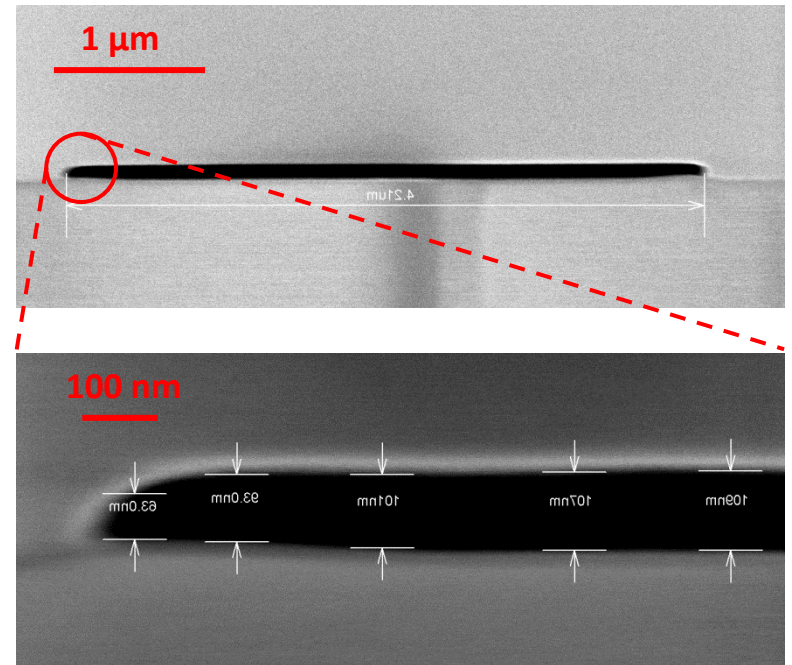
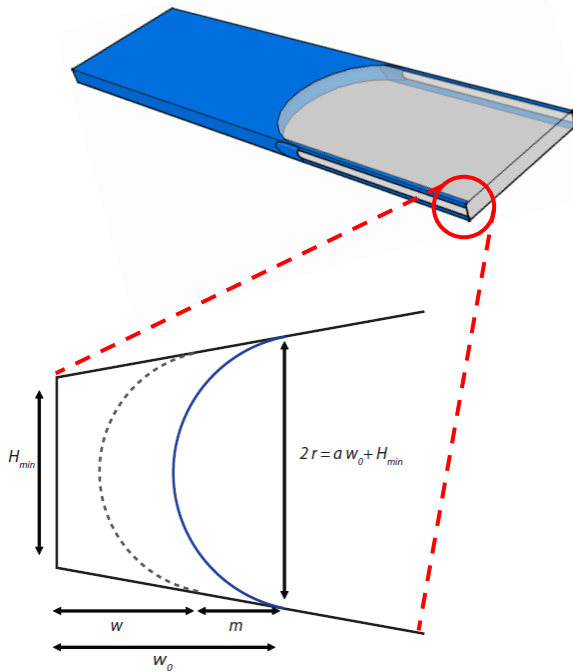


- Gas dissolution is faster for the lowest depths :
=> Higher gas concentration : $c_{eq}(\text{gas})=H \cdot P_{\text{gaz}}$
- Channel can be filled from the end !
=> end of channel is supplied by corner liquid films



Imbibition in dead end nanochannels

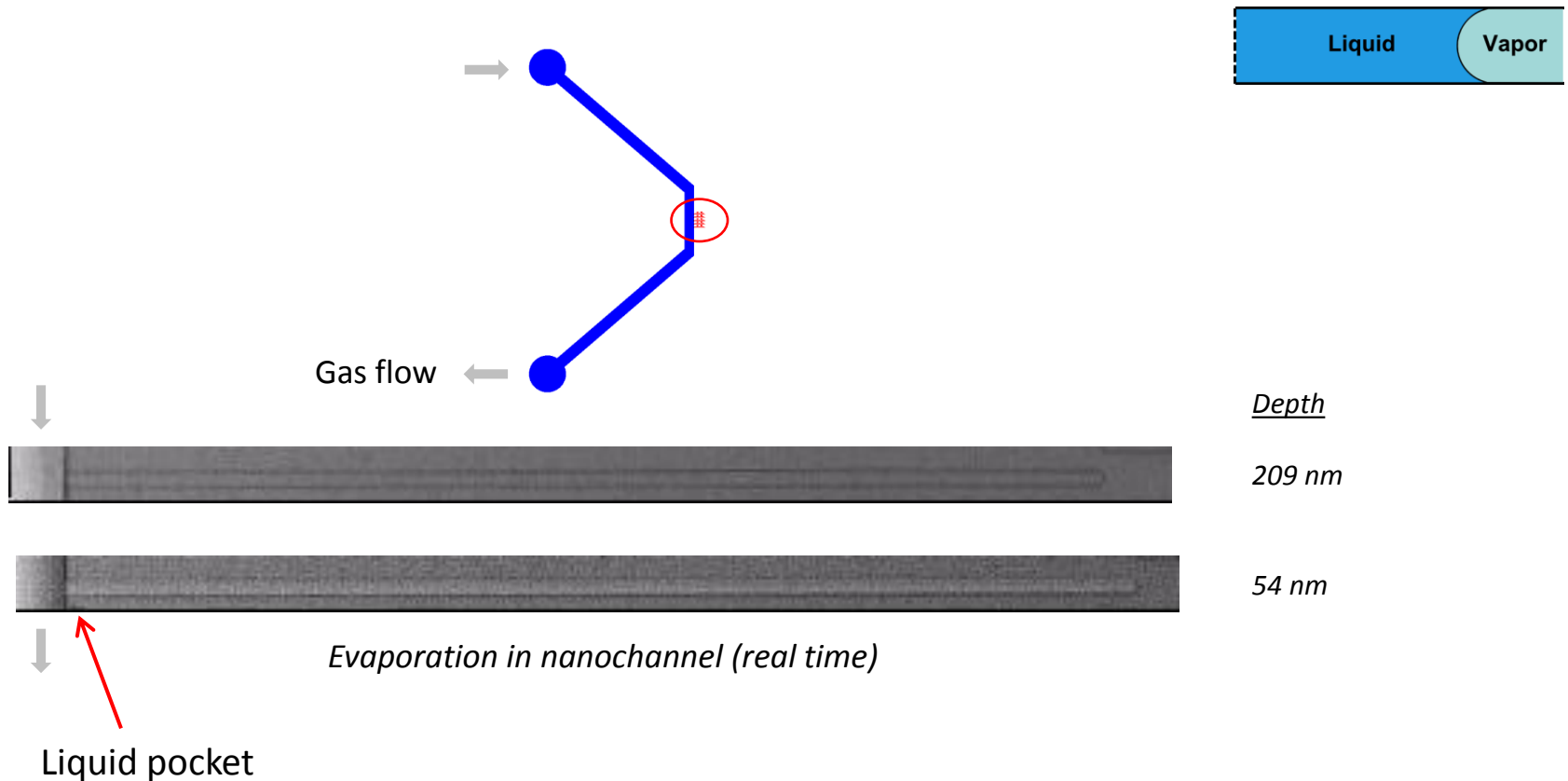
- Presence of thick liquid film if walls are not strictly parallel [1]



SEM imaging of nanochannels

[1] E. Keita, Thesis, 2014

Evaporation in dead end nanochannels



- ⇒ Presence of gas bubble modifies the kinetics of evaporation (similar in [1])
- ⇒ Evaporation from inside the liquid appears only for depth lower than 104 nm (with ethanol) (same observation as [2])

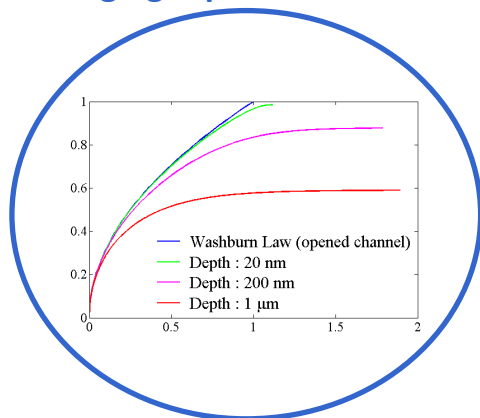
[2] C. Duan et al., *Proc. Natl. Acad. Sci. U. S. A.* (2012)

[1] O. Vincent et al., *PRL* (2014)

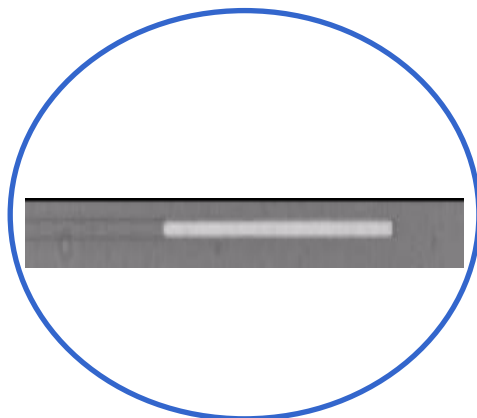
Conclusion

Two phase flow at nanometer scale presents particularities

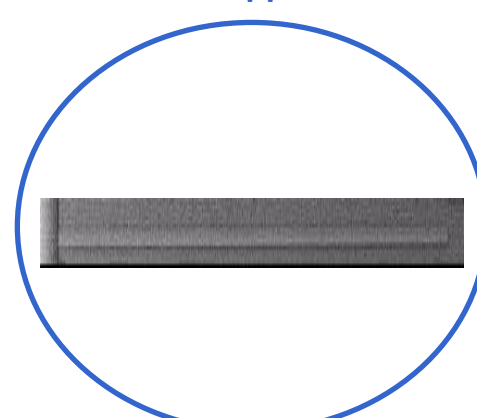
High gas pressurization



Filling from the end



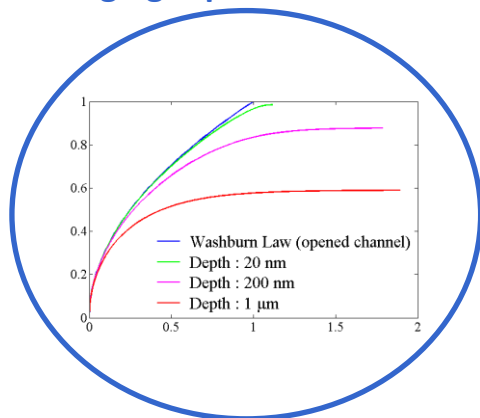
Bubbles appearance



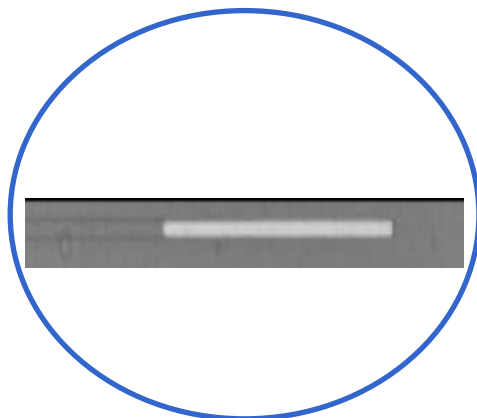
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Two phase flow at nanometer scale presents particularities

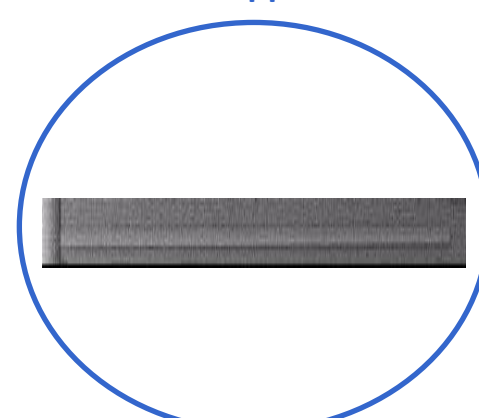
High gas pressurization



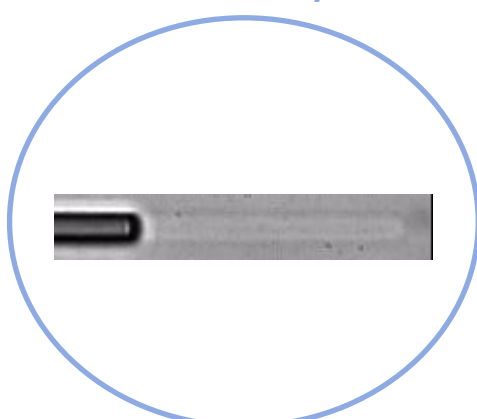
Filling from the end



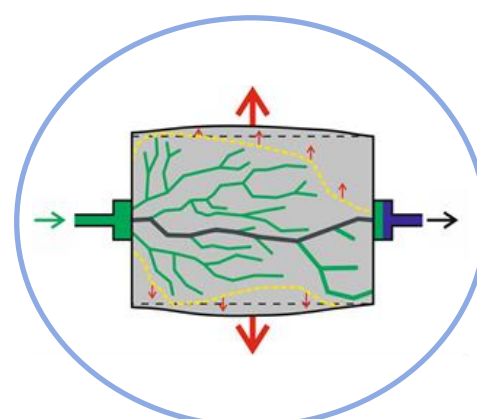
Bubbles appearance



Pore size effect on crystallization

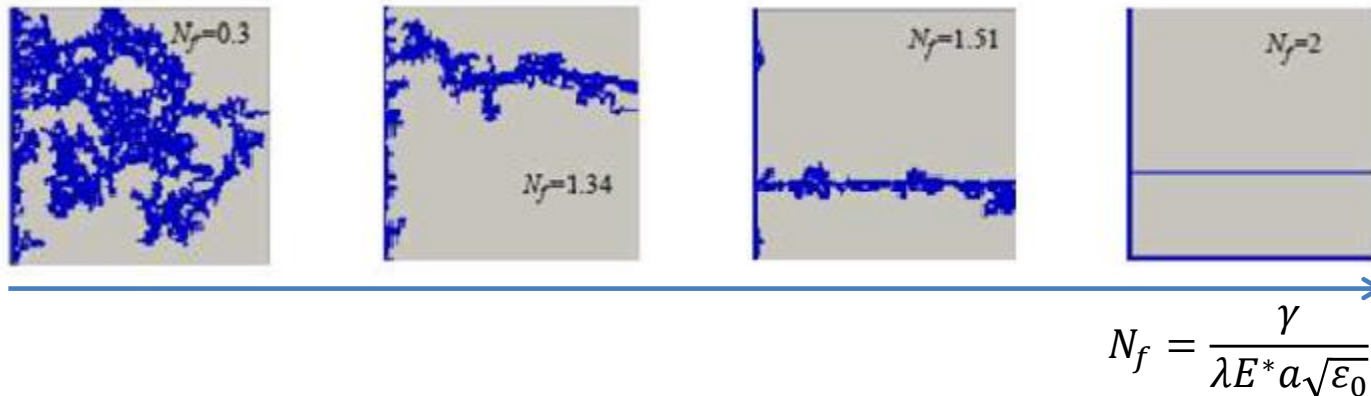
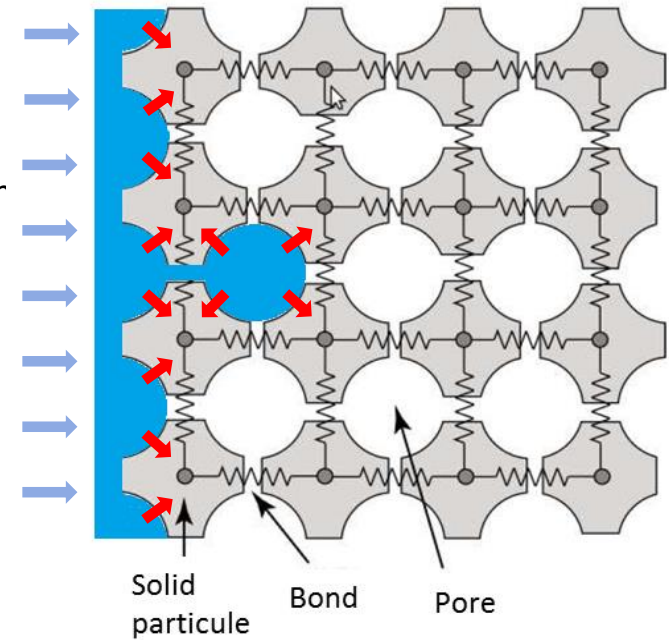


Fluid structure interaction



Perspective: deformable medium

- Approach of [1] and [2]
 - Simulation on pore network coupling:
 - Flow pore network (resolve by invasion percolation algorithm)
 - Spring network (elastic deformation)
- Goal = study the impact of deformation on invasion pattern

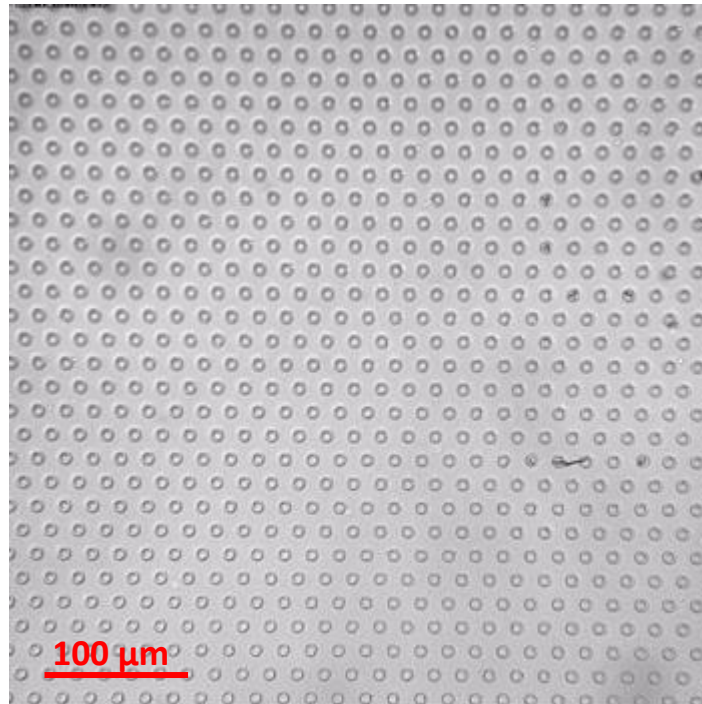
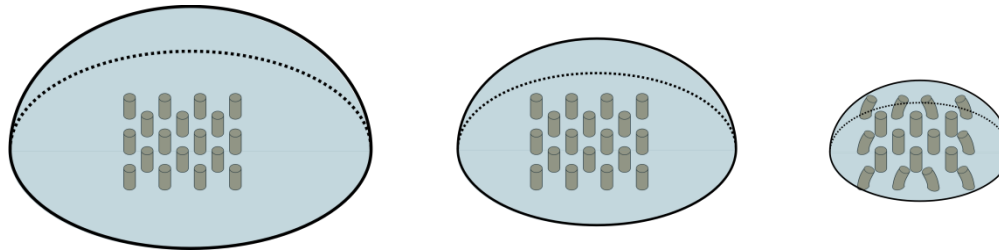


[1] Holtzman & Juanes, *Physical Review E*. (2010)

[2] P. Lefort, *PhD Thesis* (2014)

Perspective: deformable medium

- Evaporation of a droplet in a network of pillars



=> Bending and collapse of pillars by capillarity

Thank you for your attention