

**EPFL**



# Surface Structure Enhanced Microchannel Flow Boiling

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**Gautier Rouaze**

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## Pool Boiling



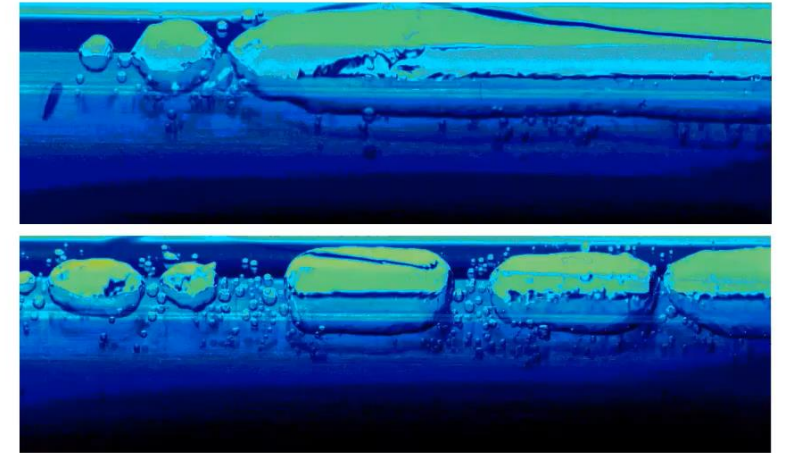
[youtube.com/shorts/xlb-f4KqfLg](https://www.youtube.com/shorts/xlb-f4KqfLg)



Flow motion source

**Flow confinement**

## Microchannel Flow Boiling

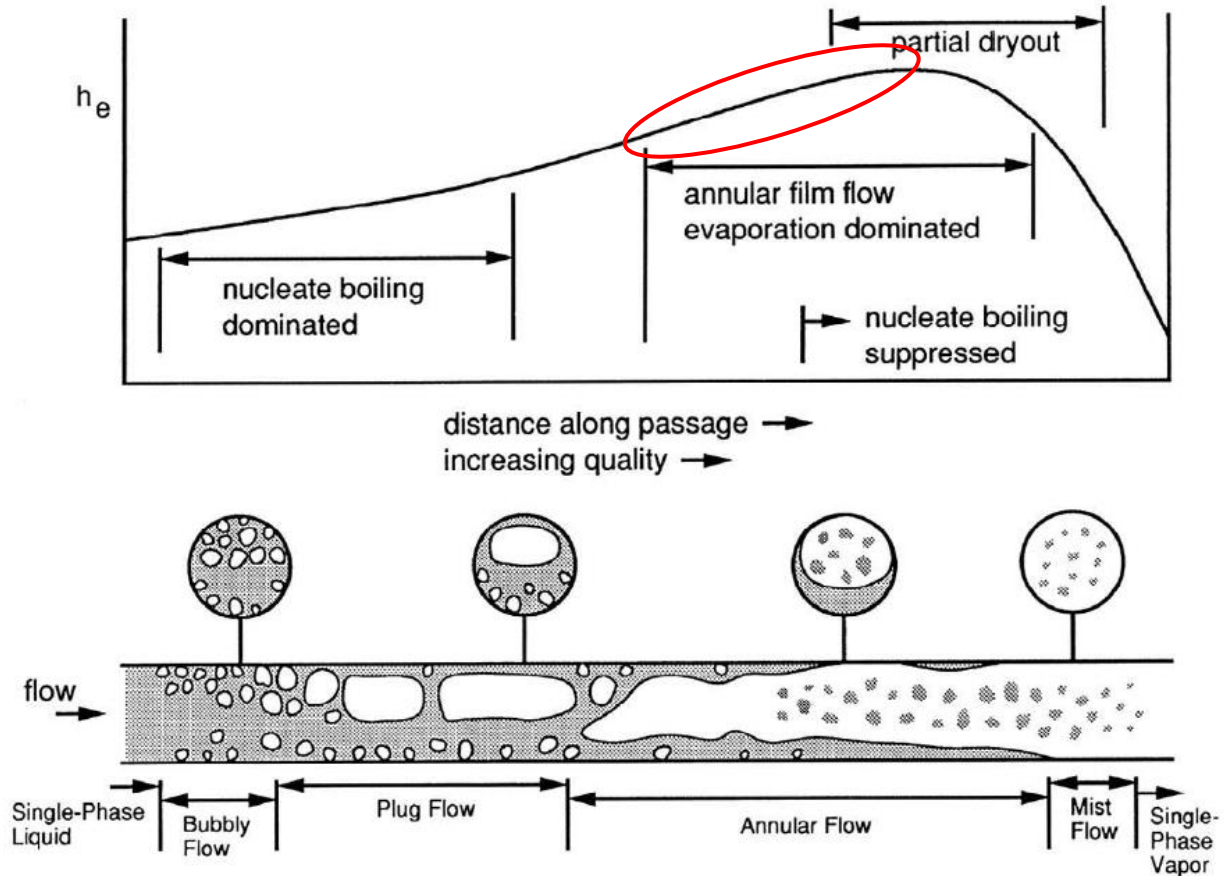


[youtube.com/shorts/HNcp7zDtwx8](https://www.youtube.com/shorts/HNcp7zDtwx8)

- Poor control and integration

- Compact and high heat flux
- **Prone to severe instabilities**

**Increase HTC and CHF while suppressing instabilities in microchannels**



- Forced convection
- Nucleate Boiling
- Film evaporation

Figure 12.1, Van Carey

## Mechanisms

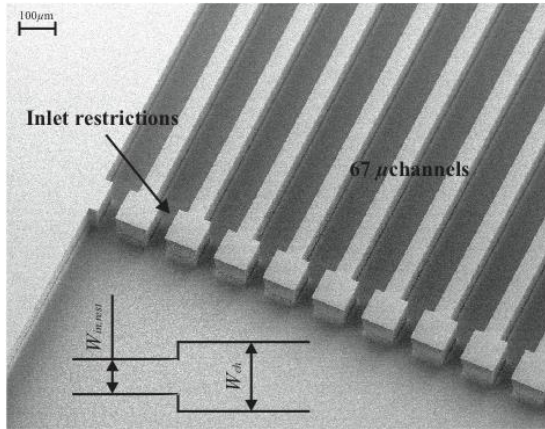
- Changes of flow pattern
- Explosive bubble expansion
- Upstream compressibility
- Density wave oscillation



## Consequences

- Leads to large pressure drop oscillations
- Local surface dryout
- Temperature spikes
- **Early CHF and device failure**

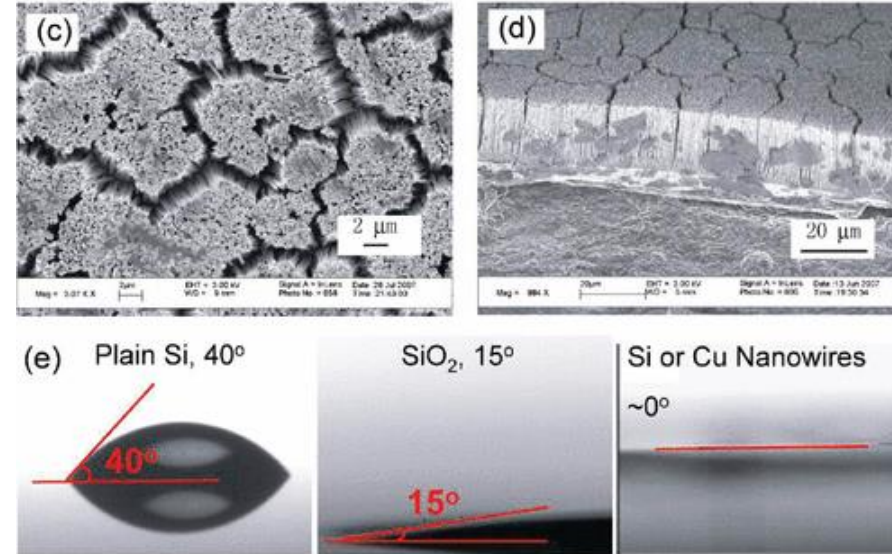
## Inlet restrictors



<https://doi.org/10.1016/j.ijheatmasstransfer.2013.08.078>

- Simple solution widely used
- Large added pressure drop

## Micro/Nanostructure-coated surfaces

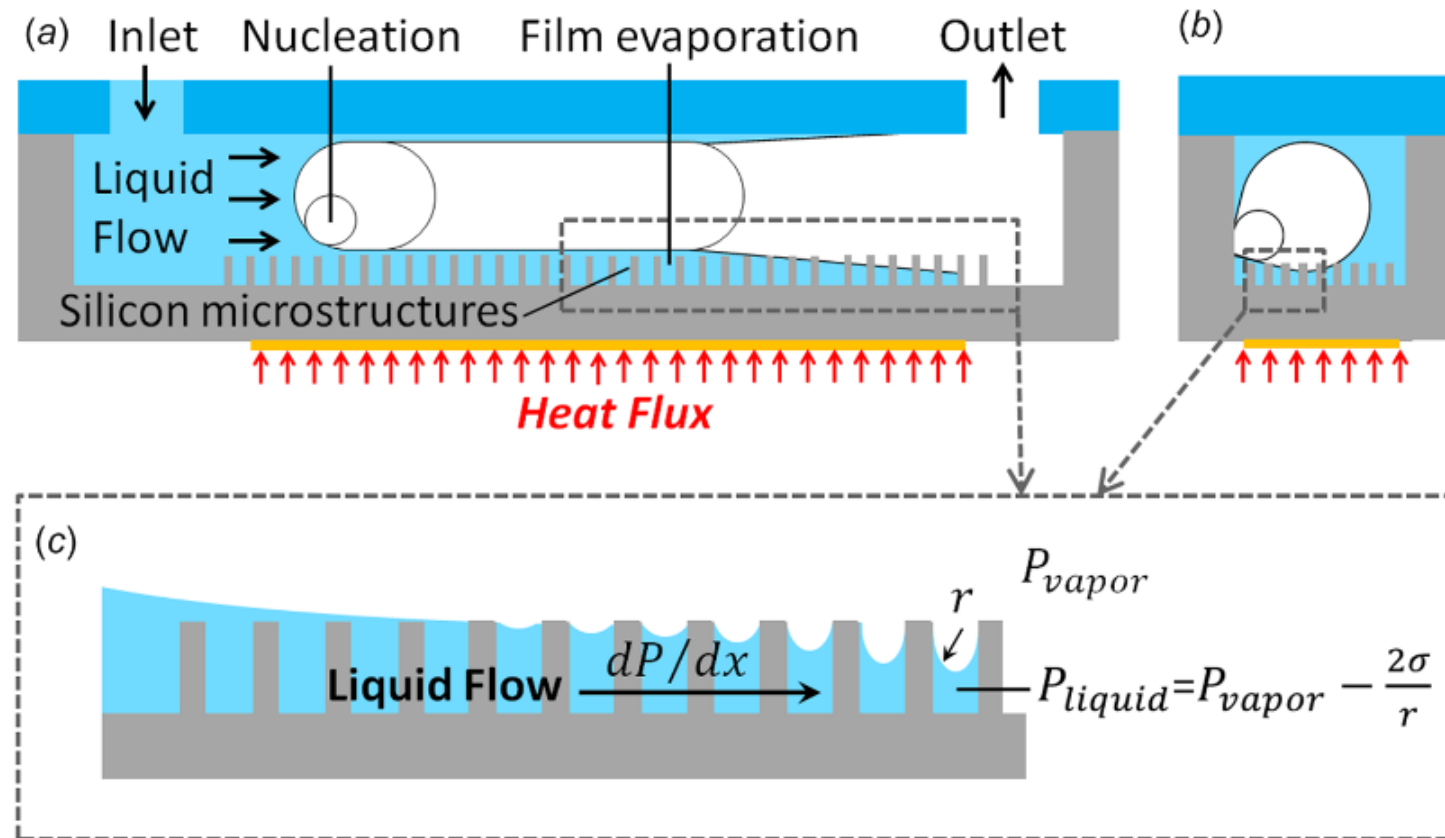


Modified surface wettability (i.e Cu nanowires)

- Superhydrophilic → Reduce the risk of dryout
- Superhydrophobic → Increase nucleation sites

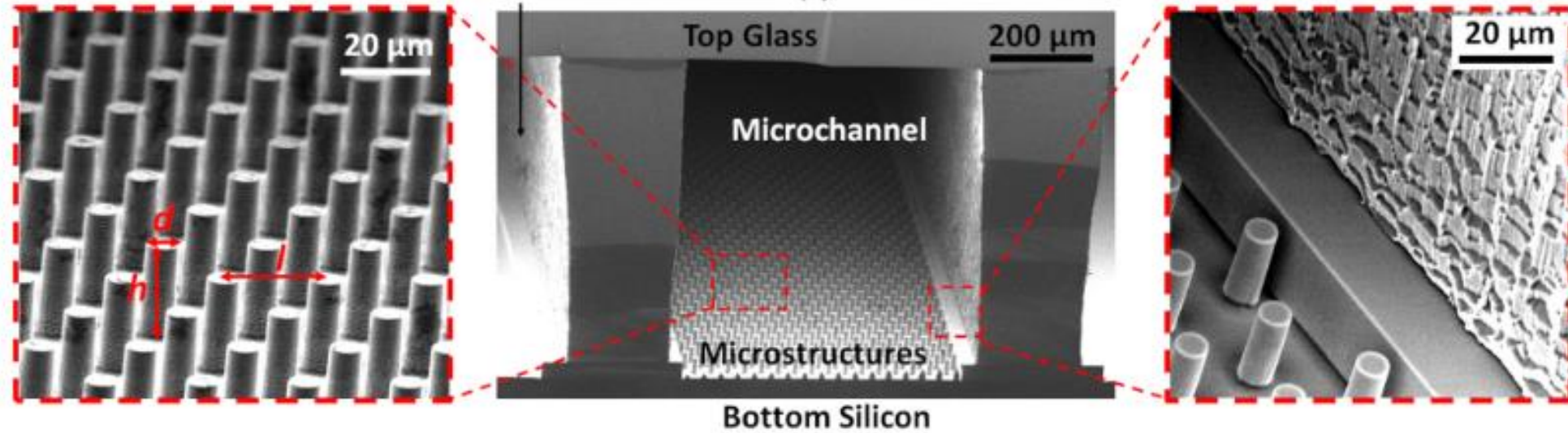
**Gap** → Need a way to stabilize annular liquid film at high heat flux

- Can we use surface microstructure to stabilize the annular film and delay dry-out ?
- Can we do this without increasing the pressure drop ?



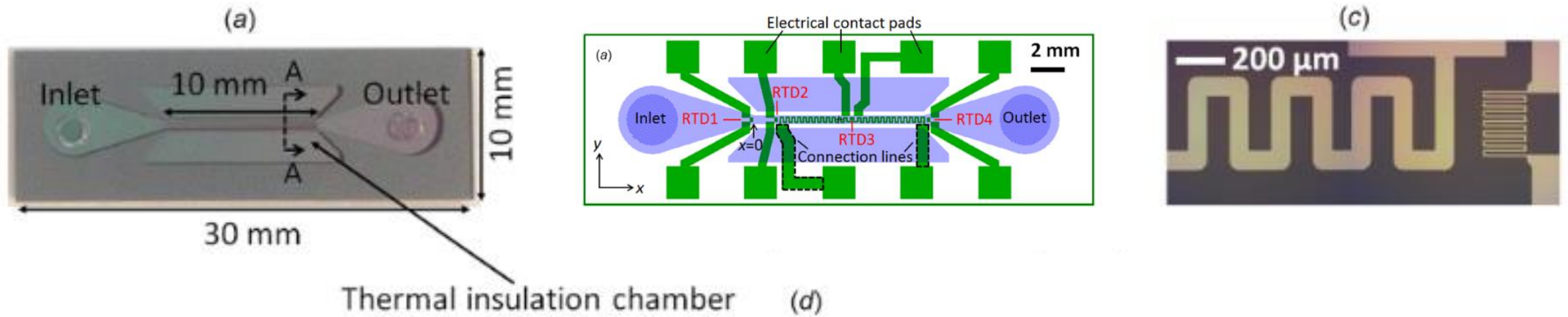
1. Micropillars in the bottom of the channels
2. Nucleation from the wall

1. Design microchannel with bottom micropillars and rough sidewall to spatially separate nucleation and thin film evaporation
2. Experimentally compare smooth vs structured channels (HTC, CHF, flow)
3. Develop simplified wicking model to understand how pillar geometry control liquid supply and CHF

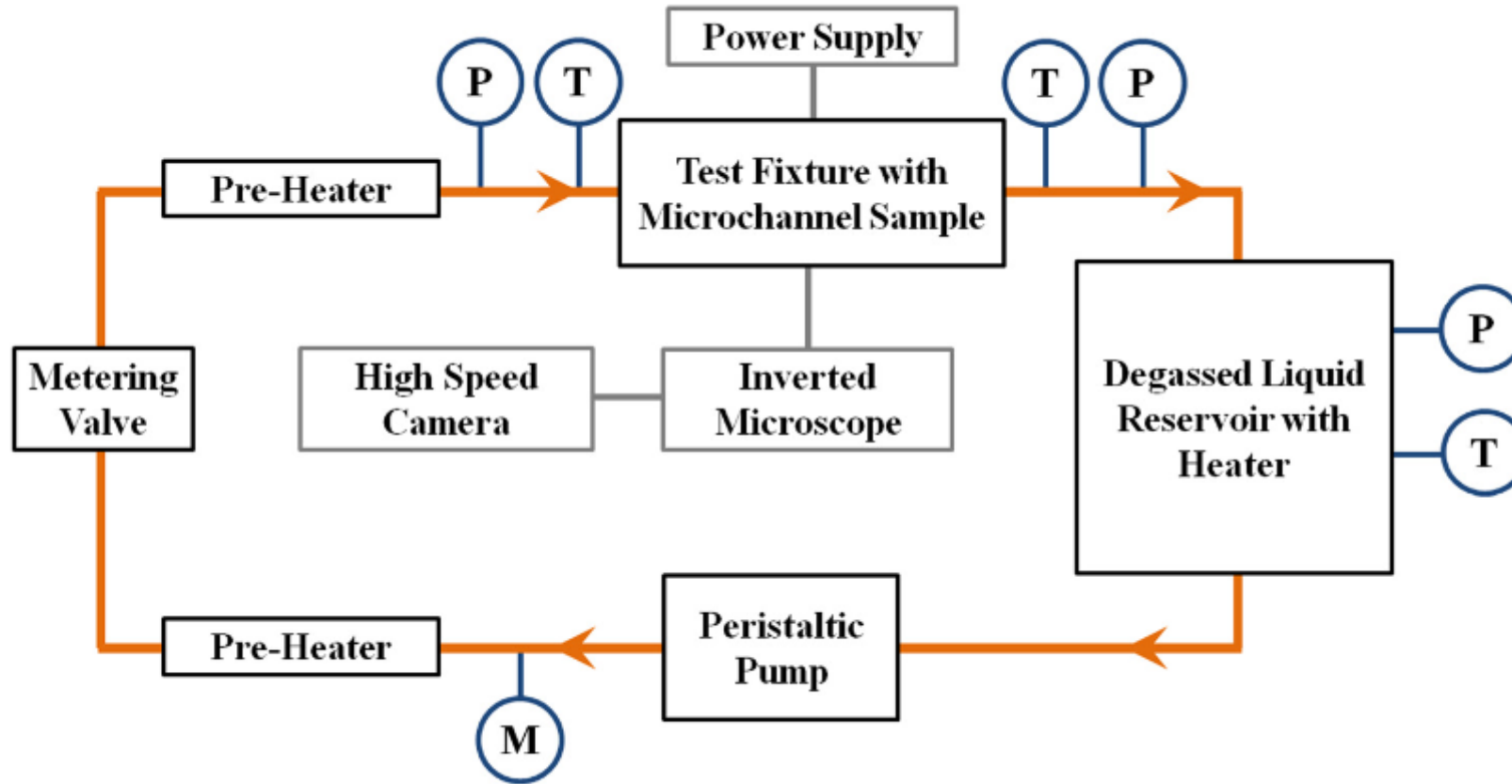


- Single 10×0.5×0.5 mm channel in Si with Pyrex top for visualization
- 4 pillar geometries S1→S4

Device no.	Height, $h$ ( $\mu\text{m}$ )	Diameter, $d$ ( $\mu\text{m}$ )	Pitch, $l$ ( $\mu\text{m}$ )
S1	25	5	10
S2	25	5	15
S3	25	10	30
S4	25	10	40



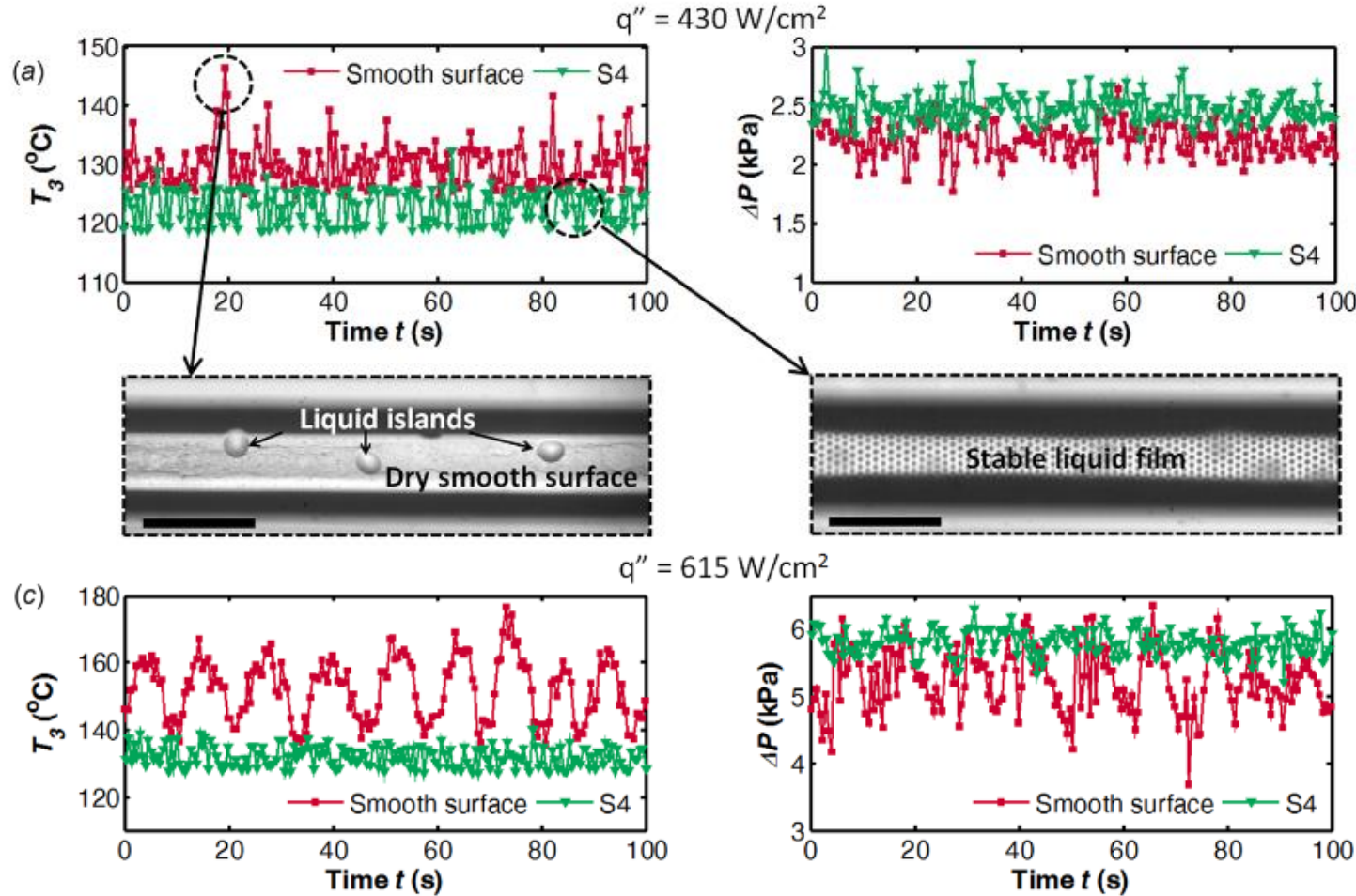
- Inlet / outlet fluid connection on the Pyrex top surface
- Thermal insulation chamber in the side
- Backside Pt heater with 4 RTD for local temperature measurements



All the tests done at a fixed mass flux of  $G = 300 \text{ kg/m}^2 \cdot \text{s}$

Temperature

Pressure drop



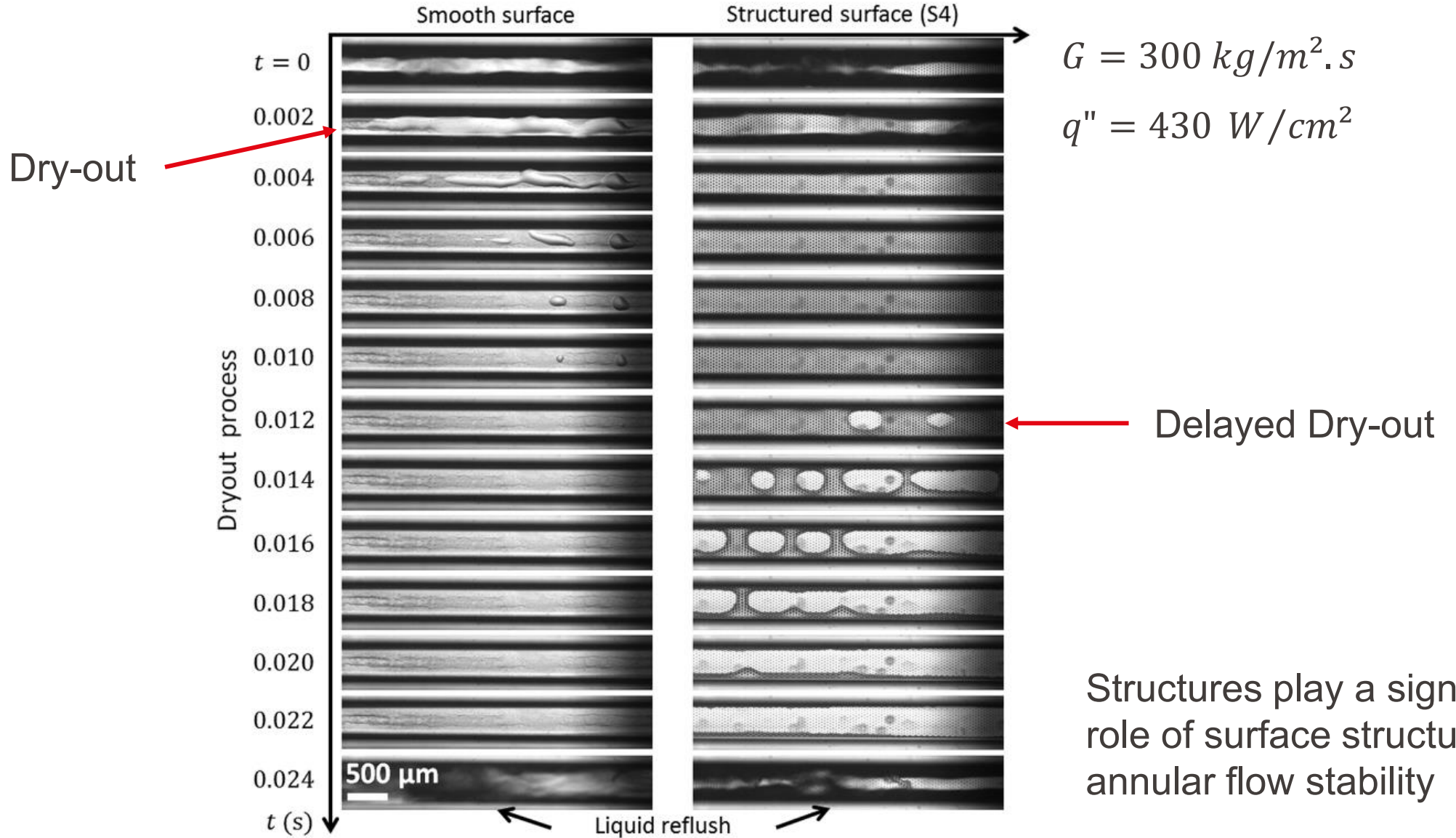
$T_3$ : temperature at the middle of the channel

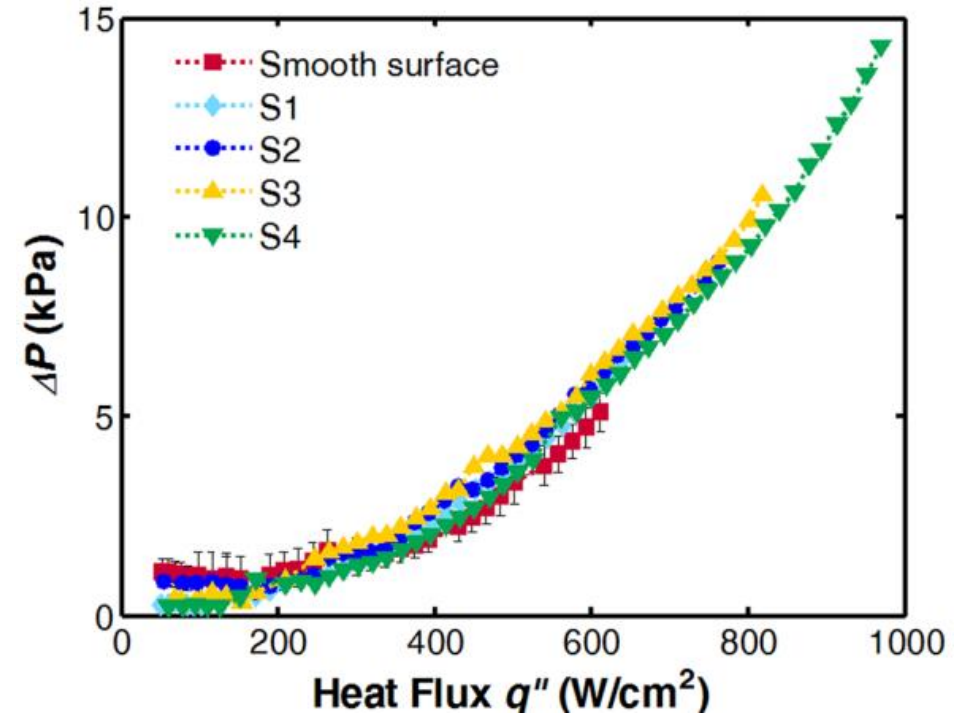
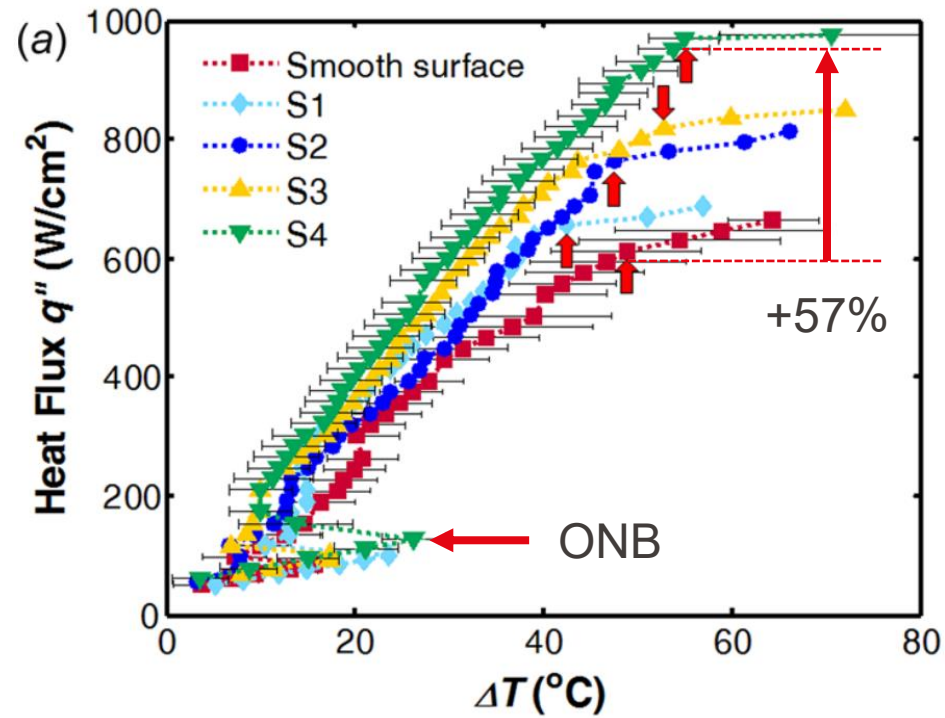
S4: best performing sample

← Close to CHF for smooth surface

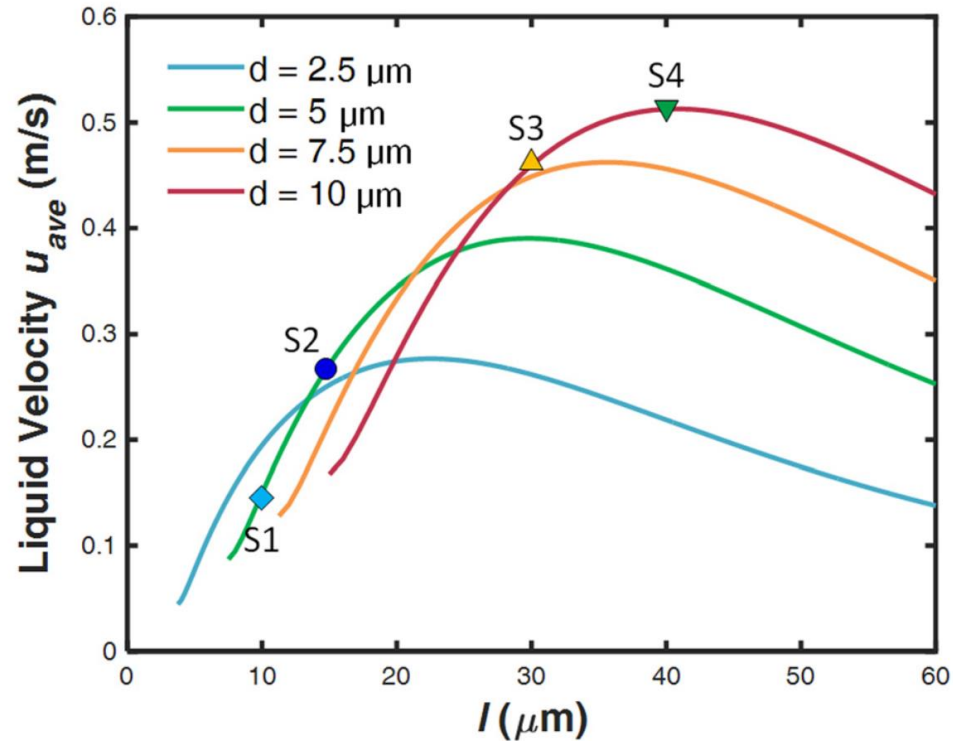
Structured surface suppresses  $T$  and  $\Delta P$  oscillations

# Dynamic dry-out process





Large **CHF** boost with no penalty in pressure drop



## Transverse Wicking Model

$$u = Ae^{\alpha\sqrt{\varepsilon}\gamma} + Be^{-\alpha\sqrt{\varepsilon}\gamma} - \frac{1}{\alpha^2\mu} \frac{dP}{dx}$$

- Solving 1D Brinkman equation for the transverse liquid velocity

$$u_{ave} = f(d, l)$$

for a fixed pillar height  $h$

- Capillary pressure  $\propto 1/l$
- Viscous drag  $\propto 1/l^2$  → Optimum pitch

# Limitations & Open questions

## Range of conditions

- Only one mass flux studies ( $300 \text{ kg/m}^2\text{s}$ )
- One fluid (water) → Refrigerant (lower surface tension) / dielectric fluid
- Single channel geometry → multichannel instability not discussed

## Scaling to real devices

- Manufacturing cost
- Durability / fouling over time

**Problem:** Flow boiling instabilities limit the use of microchannel flow boiling in industrial application

**Solution:** Superhydrophilic micropillars with rough sidewall decouple nucleation and thin-film evaporation and generate capillary wicking

**Benefit:** Stable  $T$  and  $\Delta P$  near CHF, +57% CHF for the same pressure drop



**Thank you !**

**Questions & Answers**