SPONTANEOUS DROPLET MOTION ON MICROPATTERNED ALUMINIUM FOR IMPROVED EFFICIENCY OF HEAT-EXCHANGERS AND WIND TURBINES

Kirill Misiiuk
Sam Lowrey, Richard Blaikie, Andrew Sommers

THE PROBLEM TO BE SOLVED

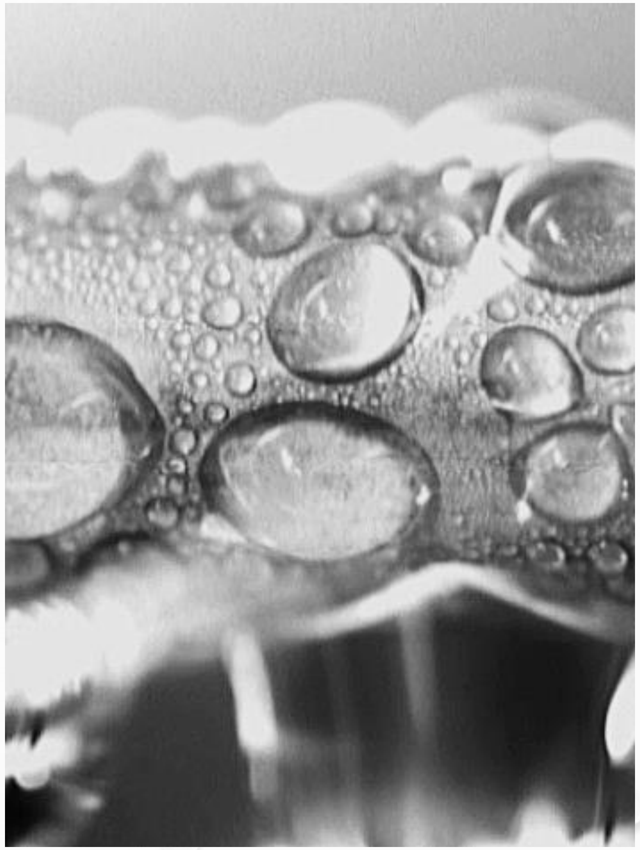
Wind turbines

Icing might cause:

- full stop (7-8% of a working time);
- disruption of aerodynamics (20-50 % of power loss);
- higher deterministic loads and asymmetric masses;
- excitation of edgewise vibrations or resonance effects.

Bryan Preston
PJ Media
17 February 2021

Heat-exchangers



David L. Chandler
MIT News Office
21 June 2013

Condensation might cause:

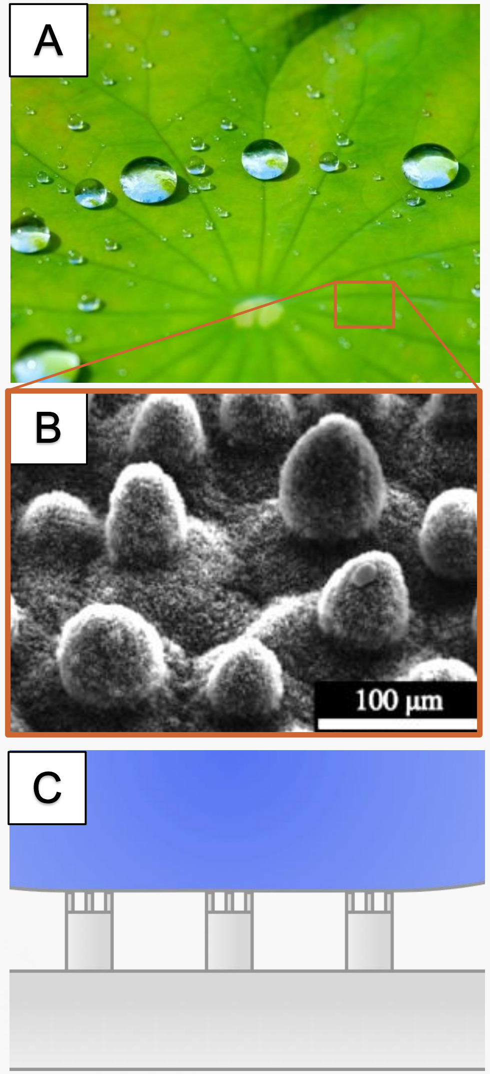
- the restriction of flow and the increasing of the pressure drop;
- decreasing of the heat transfer area;
- increasing of the thermal resistance;
- great energy conversion loss;

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

THE INSPIRATION

“Lotus effect”

hierarchical surface consists of random microscale bumps with superimposed nanoscale hairs



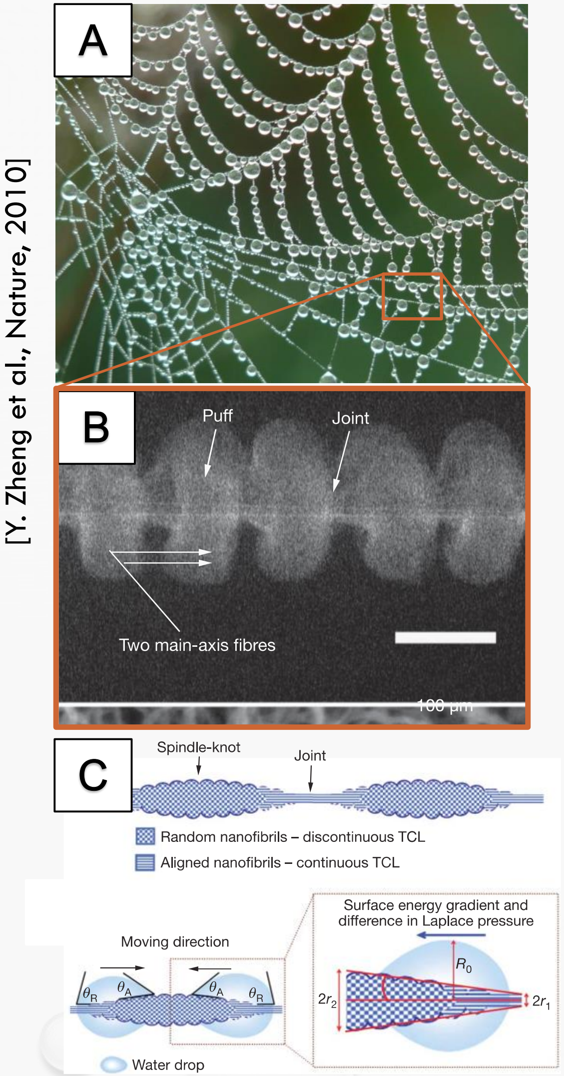
[H. Zhang et al., Colloids Surf A: Physicochem. Eng. Aspects, 413, 2012]

(A) A lotus leaf with spherical water droplets on its surface;
(B) SEM-photos of a hierarchical structure on a lotus leaf surface;
(C) An illustration of a droplet sitting on top of a hierarchical structure.

Spider silk water moving

different interaction between water and the silk at the knots and joints

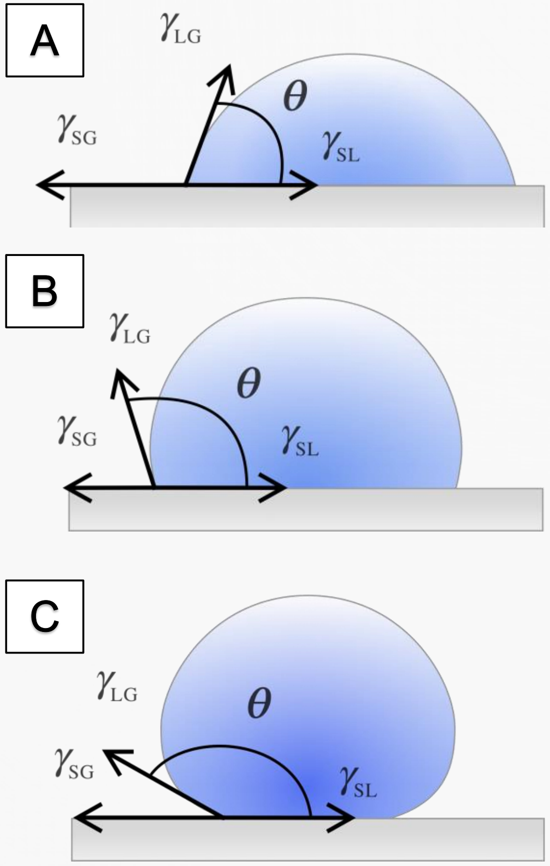
[Y. Zheng et al., Nature, 2010]



(A) collected droplets on wetted spider silk;
(B) SEM-photos of puff and joints of silk of cribellate spider;
(C) Schematic of the mechanism of water collection.

FUNDAMENTALS: STATICS

Solid-liquid interaction

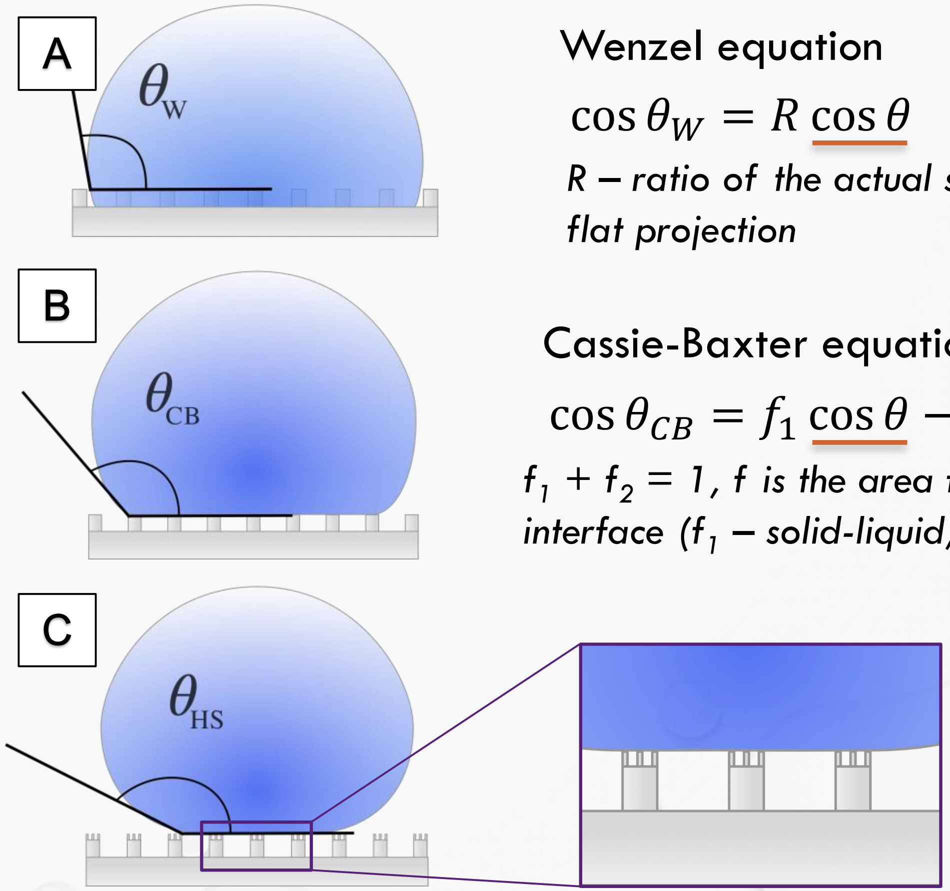


Young's equation

$$\gamma_{SG} = \gamma_{SL} + \gamma_{LG} \cos\theta$$

Contact angle of a flat surface.
(A) hydrophilic (*HPL*, 0°< $\theta \leq$ 90°),
(B) hydrophobic (*HPB*, 90° $\leq \theta <$150°),
(C) superhydrophobic (*SHPB*, $\theta \geq$150°).

Wetting states



Wenzel equation

$$\cos\theta_W = R\cos\theta$$

R – ratio of the actual surface to the flat projection

Cassie-Baxter equation

$$\cos\theta_{CB} = f_1\cos\theta - f_2$$

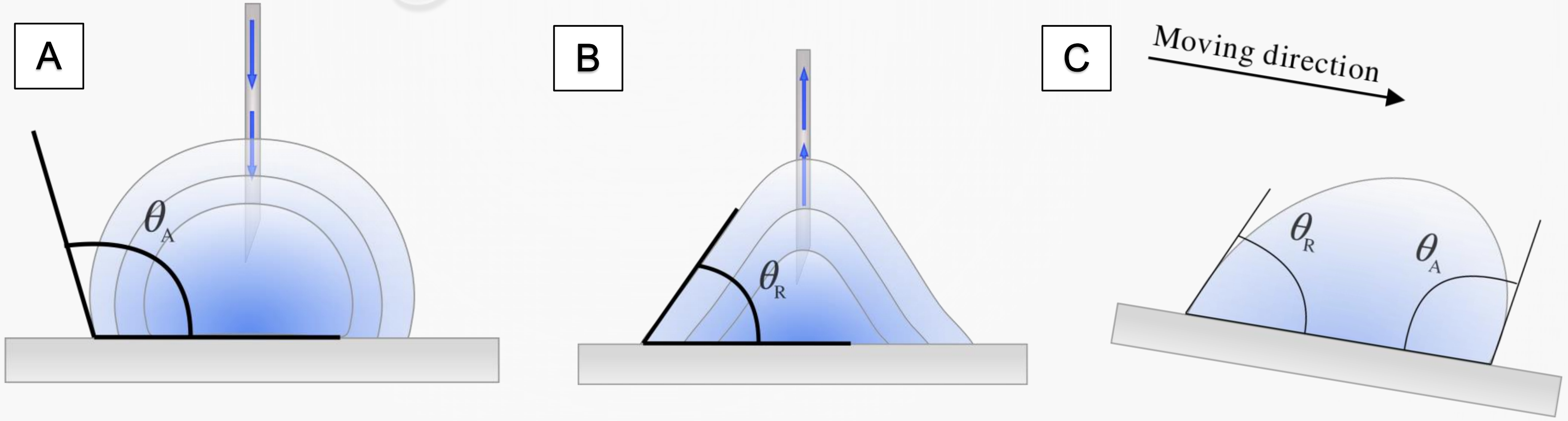
$f_1 + f_2 = 1$, f is the area fraction of an interface (f_1 – solid-liquid, f_2 – liquid-air)

An illustration of the differences of contact models:
(A) Wenzel's model,
(B) Cassie-Baxter's model,
(C) Hierarchical structure with CB-CB states.

FUNDAMENTALS: DYNAMICS

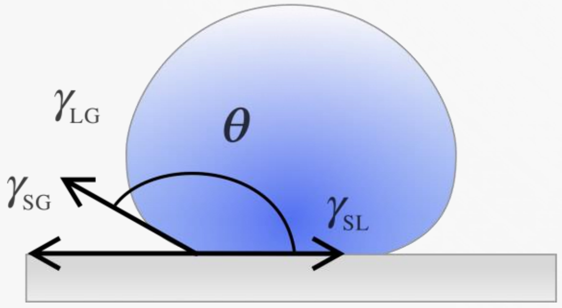
Contact angle hysteresis

$$CAH = \theta_A - \theta_R$$



Schematic of a contact angle hysteresis measurement by (A) increasing and (B) decreasing of a droplet volume; (C) "tilting plate"-method, where a droplet is moving over the surface.

$$\theta_R \leq \theta \leq \theta_A$$



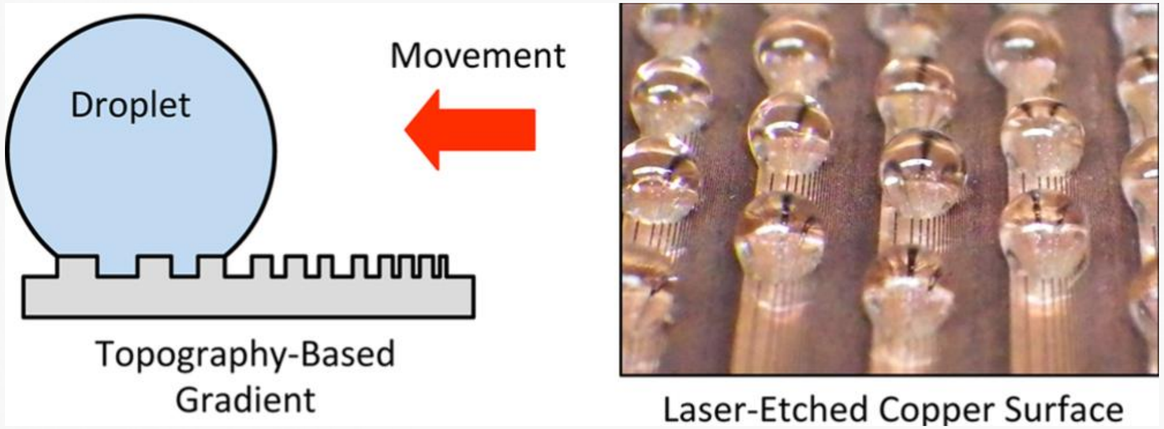
Criteria of superhydrophobicity:

CA (θ) $\geq 150°$, ⟵ Less interaction with the surface

CAH $\leq 15°$ ⟵ Easy to slide/roll off

TOPOGRAPHY GRADIENT IDEAS

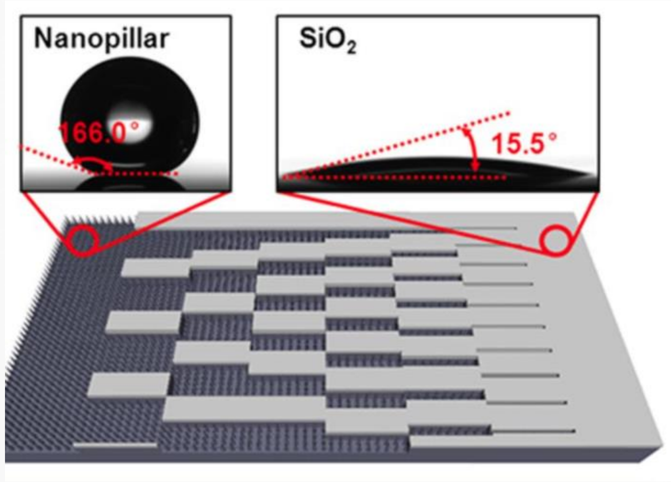
Microgrooves



A. D. Sommers et al., Langmuir, 2013, 29, 12043−12050

- made on copper;
- Wenzel state (not superhydrophobic);
- relatively short travel distance;

Stripes

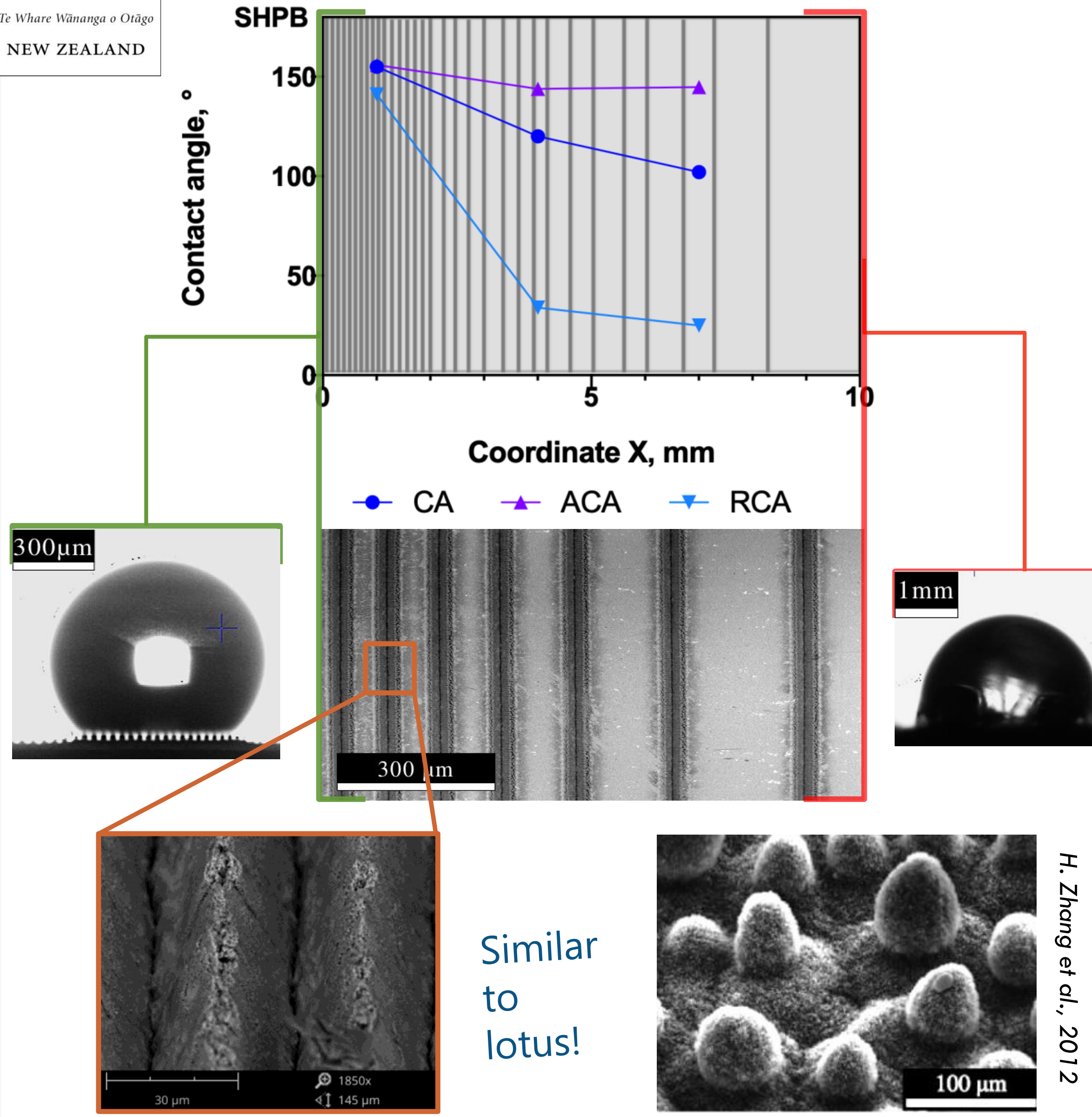


C. Liu et al., Sci Rep, 2017, 7, 7552

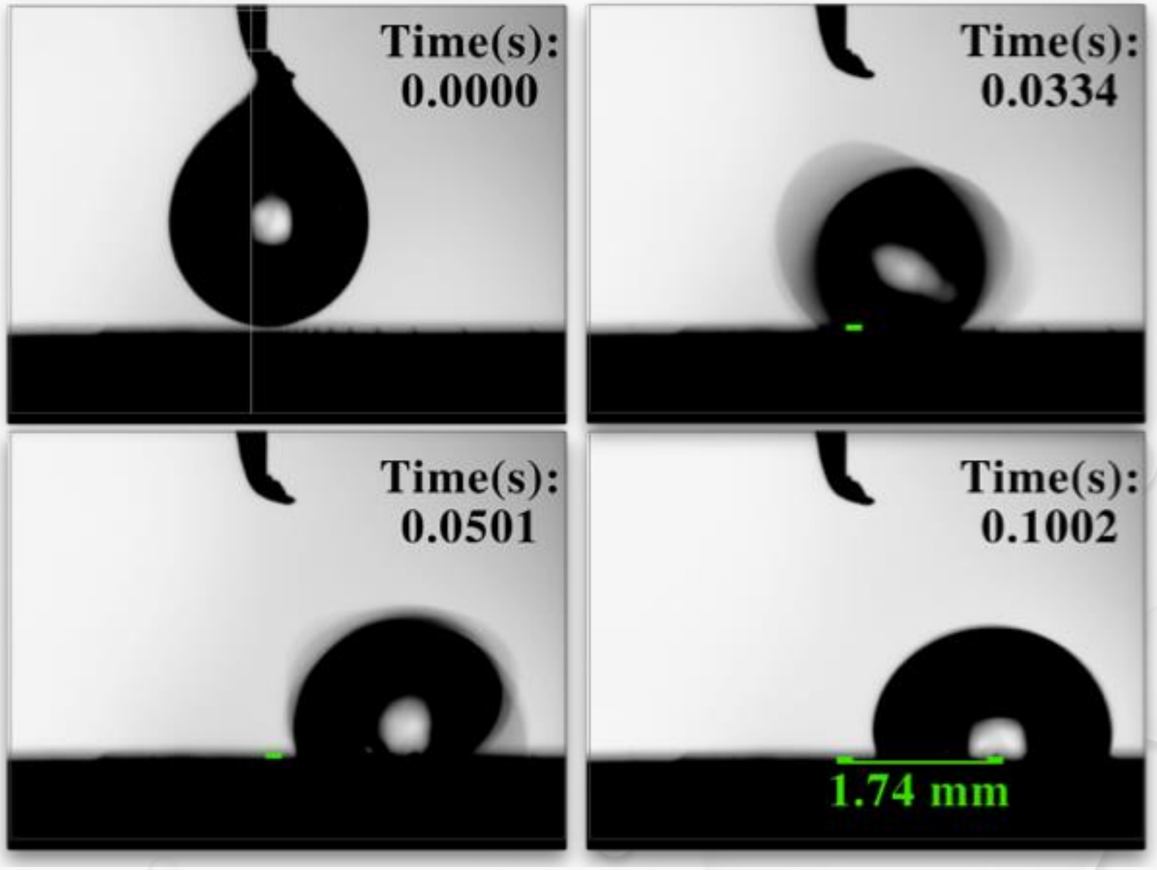
- made on silica/SiO_2;
- all wetting states along the gradient;
- relatively long travel distance;

SUPERHYDROPHOBIC ALUMINIUM GRADIENT

Design features

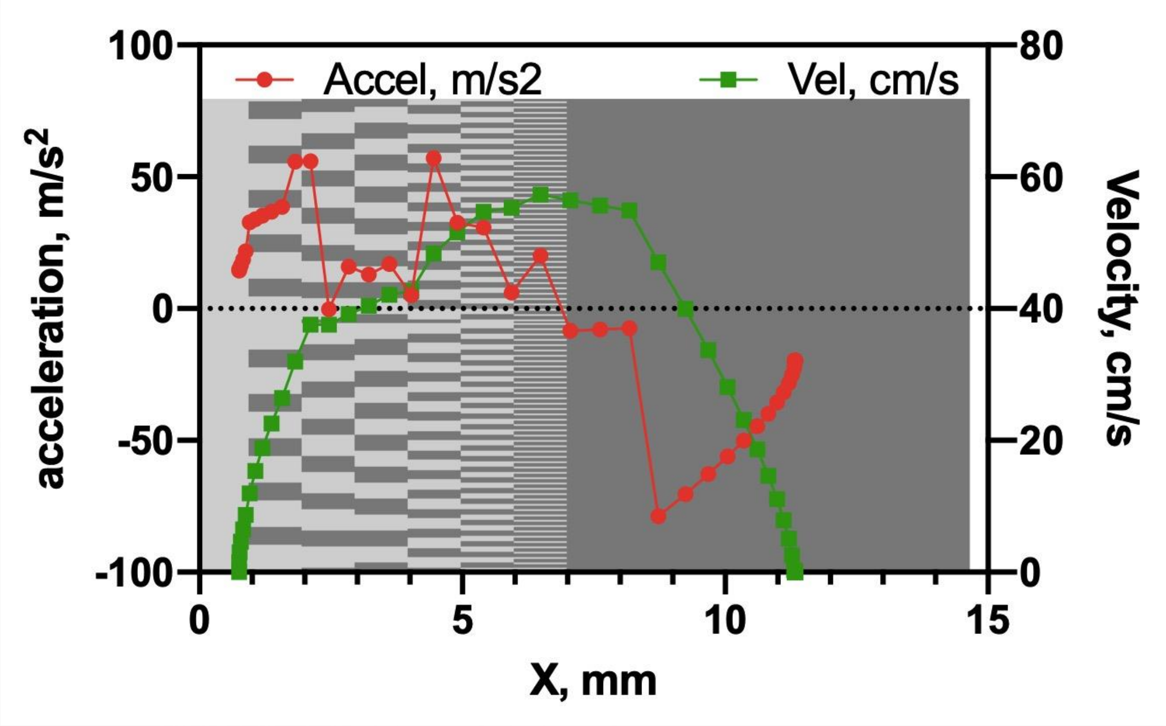


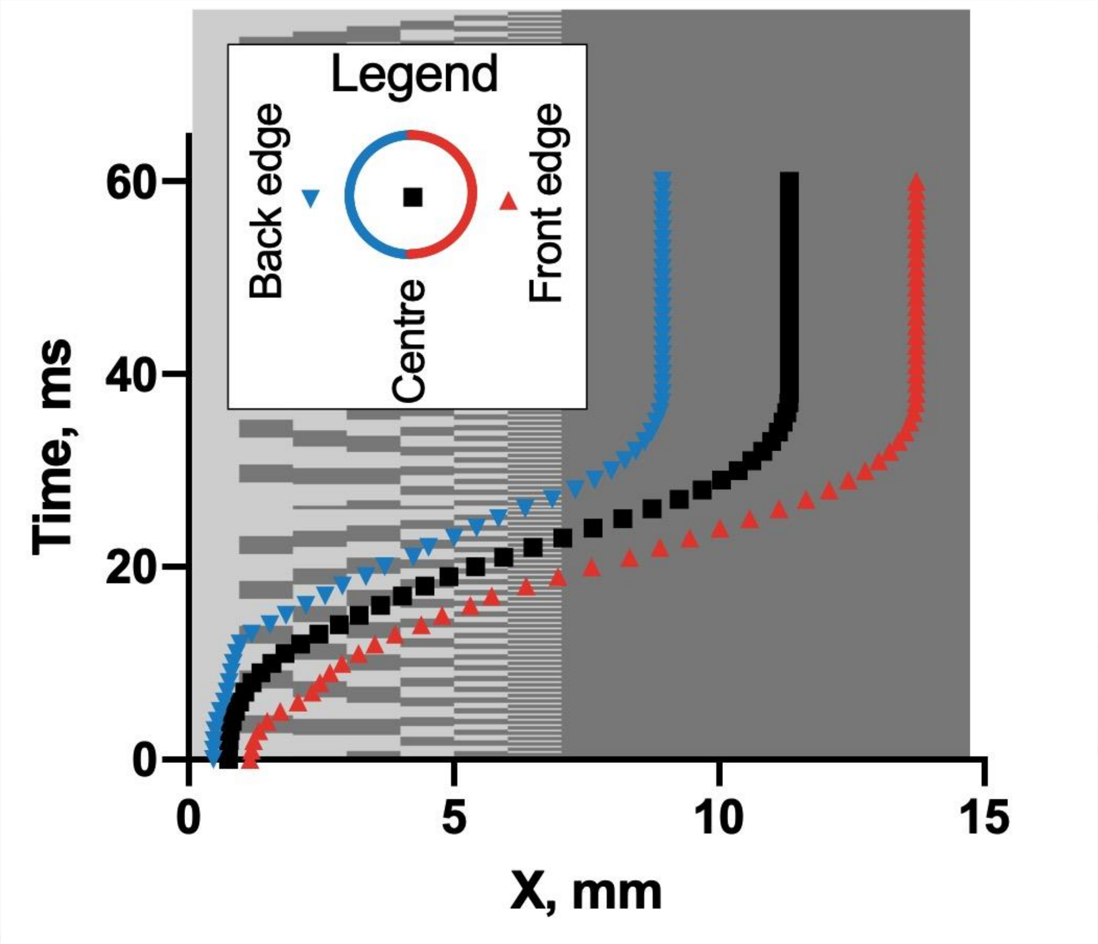
Working principle



Spontaneous droplet motion for almost 2 mm after gentle deposition

TOPOGRAPHY GRADIENT MODELLING





Results of the modelling of the silica/SiO_2 stripe gradient shown by *C. Liu et al., Sci Rep, 2017, 7, 7552*

UNIVERSITY of OTAGO

Te Whare Wānanga o Otāgo

NEW ZEALAND

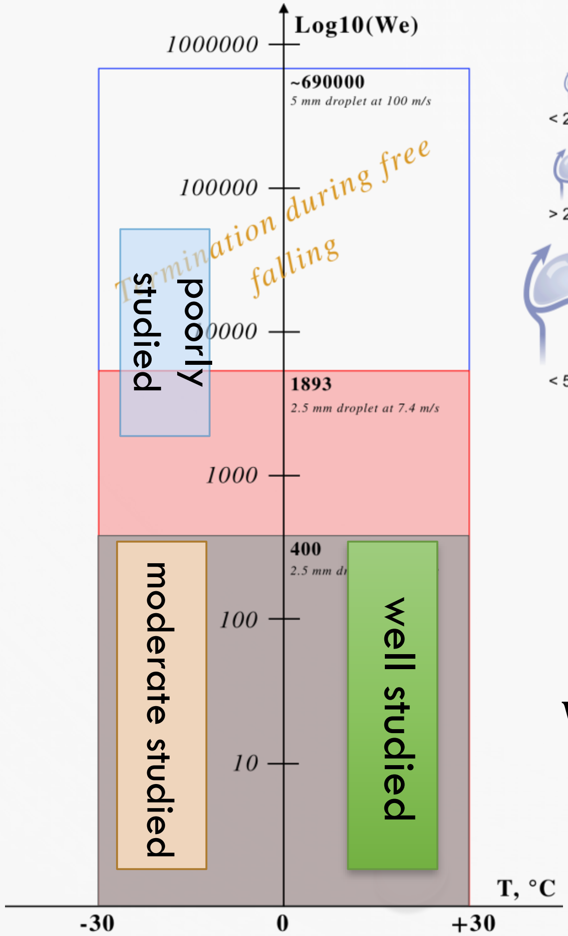
Ministry of Business, Innovation & Employment

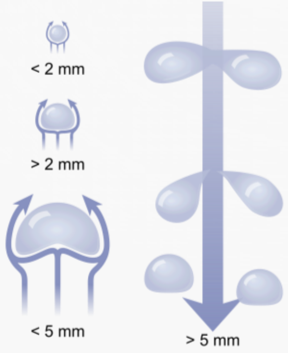
The MacDiarmid Institute for Advanced Materials and Nanotechnology

SPONTANEOUS DROPLET MOTION ON MICROPATTERNED ALUMINIUM FOR IMPROVED EFFICIENCY OF HEAT-EXCHANGERS AND WIND TURBINES

- ✓ Water-repellent properties of micropatterned aluminium are shown;
- ✓ Gradient structures are designed and produced;
- ✓ Spontaneous droplet motion is shown;
- ✓ Theoretical and numerical explanation is provided;

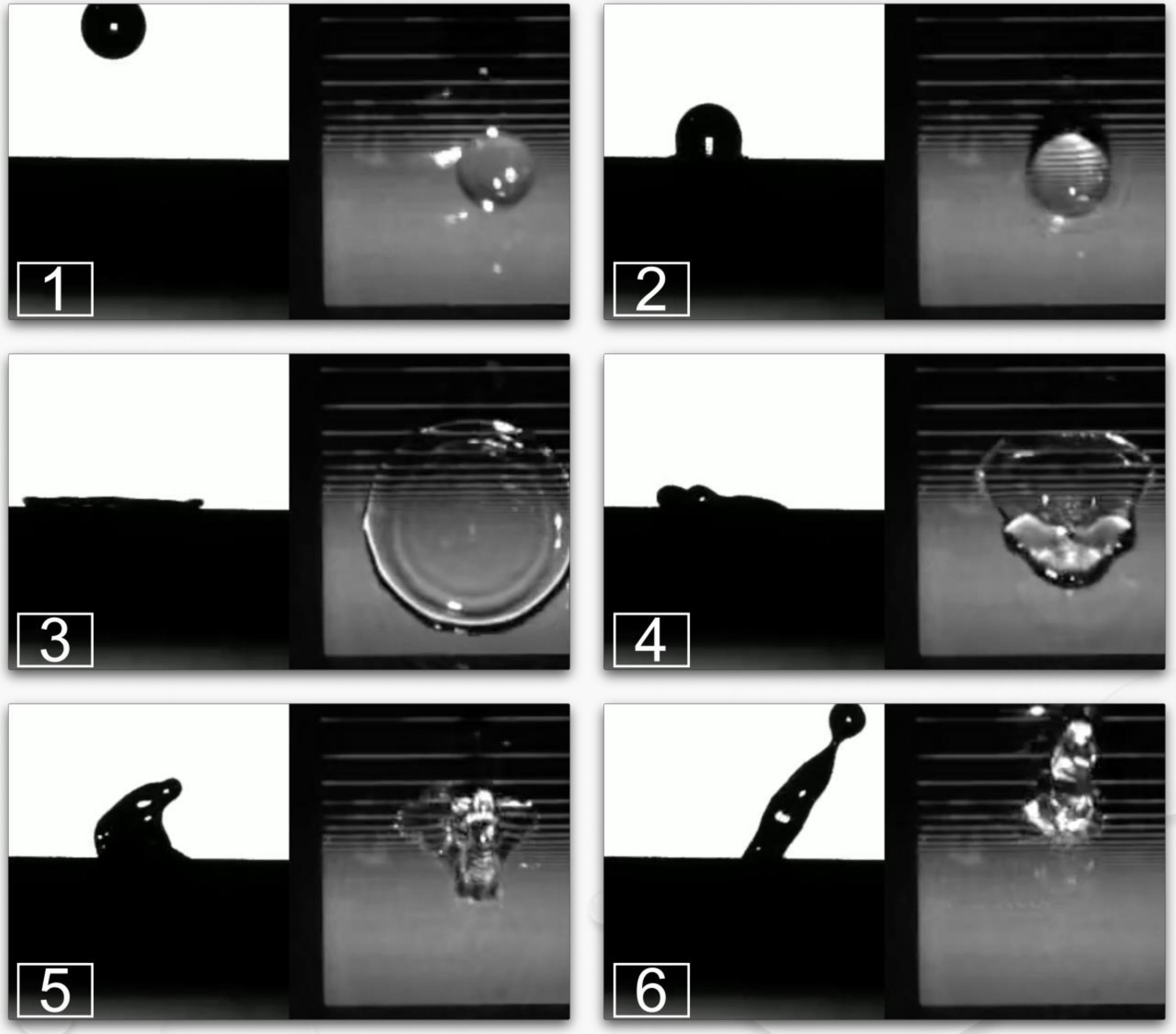
FURTHER WORK: DROP IMPACT





We – Weber number

$$We = \frac{\rho \vartheta^2 D}{\gamma}$$



Room temperature drop impact test. The directional rebounding of the impacted droplet towards the gradient vector has been observed. (in collaboration with Assoc. Prof. Geoff Willmott and Santosh Pandian, University of Auckland)

UNIVERSITY of OTAGO
SAPERE AUDE
Te Whare Wānanga o Otāgo
NEW ZEALAND

Ministry of Business, Innovation & Employment

The MacDiarmid Institute for Advanced Materials and Nanotechnology

SPONTANEOUS DROPLET MOTION ON MICROPATTERNED ALUMINIUM FOR IMPROVED EFFICIENCY OF HEAT-EXCHANGERS AND WIND TURBINES

Kirill Misiiuk
Sam Lowrey, Richard Blaikie, Andrew Sommers

Thank you for your attention!