Surfaces with Extreme Wettability

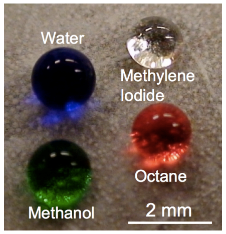
Anish Tuteja

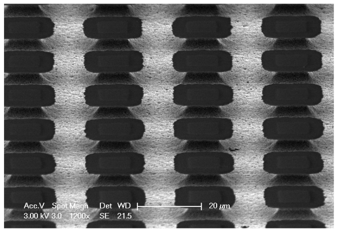
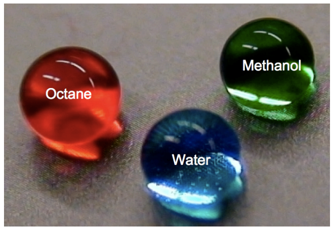
Department of Materials Science and Engineering, University of Michigan

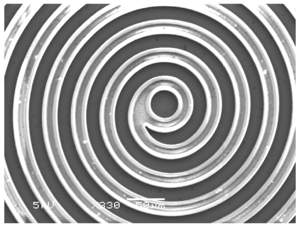
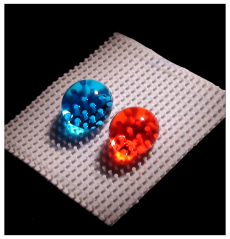
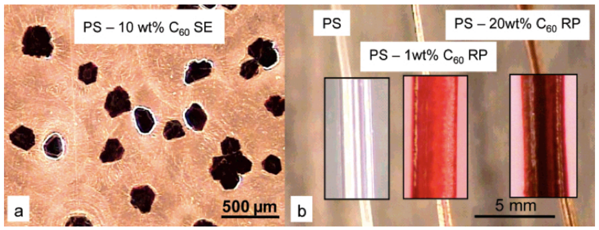
Department of Macromolecular Science and Engineering, University of Michigan

Department of Chemical Engineering, University of Michigan

Polymers, Surfaces and Interfaces (PSI -ψ) group

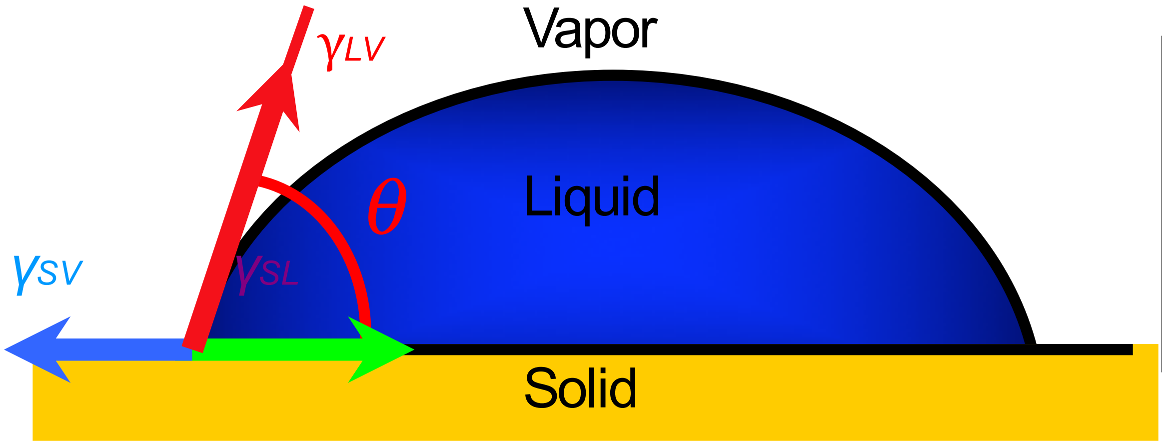


Superoleophobic surfaces

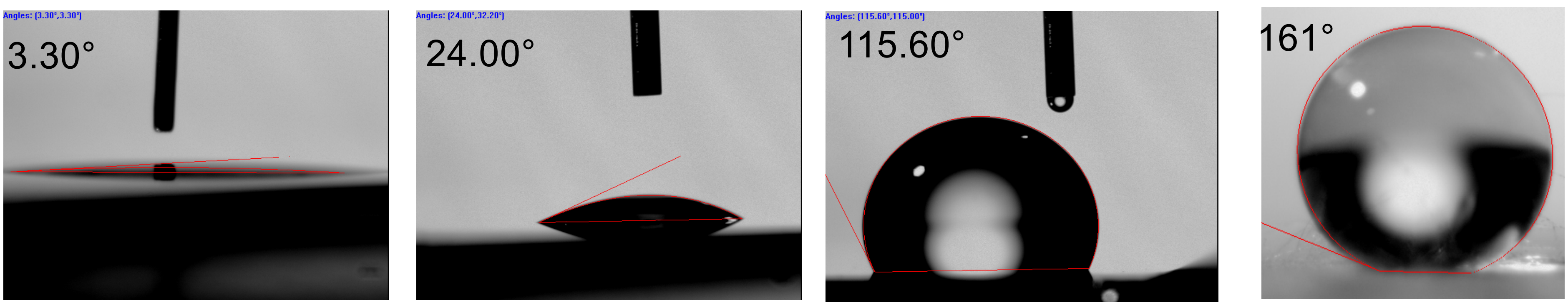
Young's Equation (1805)



$$\gamma_{SV} = \gamma_{LV} \cos\theta + \gamma_{SL}$$

$$\cos\theta = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}}$$

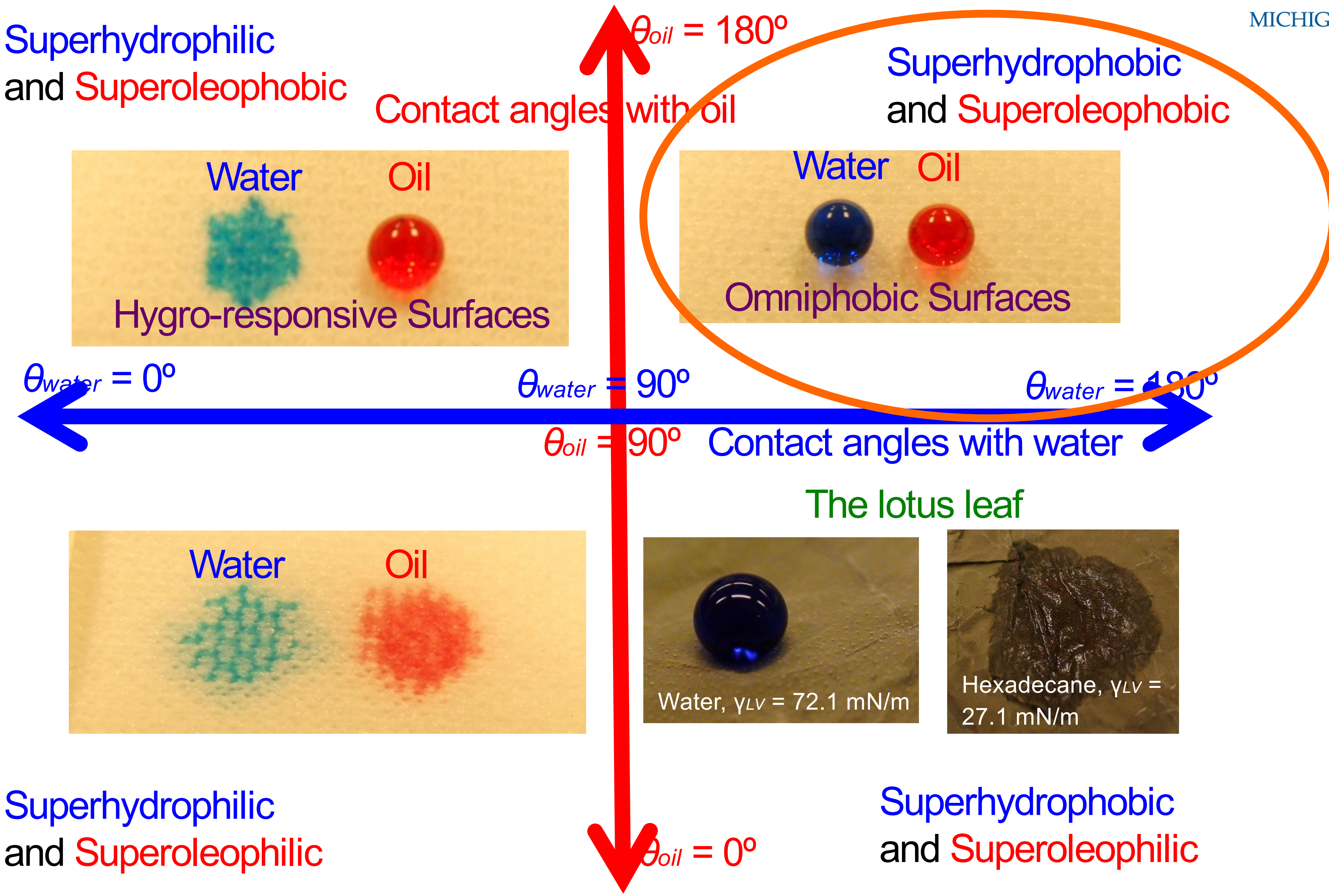
Contact angles with water:



Superhydrophilic	Hydrophilic	Hydrophobic	Superhydrophobic
$\theta \sim 0°$	$0° < \theta < 90°$	$\theta > 90°$	$\theta^* > 150°$, low hysteresis

Similarly, superoleophobic surfaces display contact angles $\theta^* > 150°$ and low hysteresis with oils or alkanes

The wettability landscape



Designing superoleophobic surfaces

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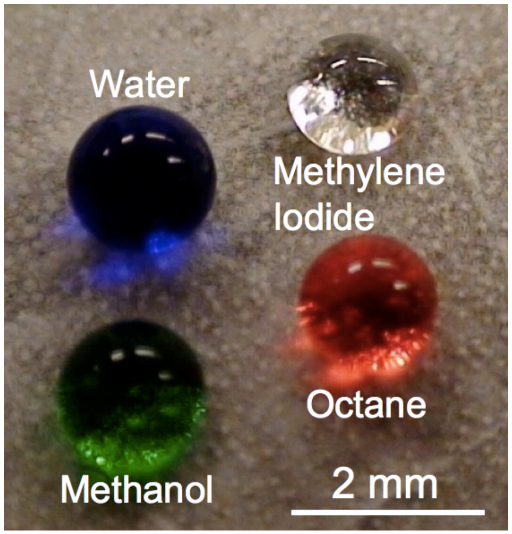
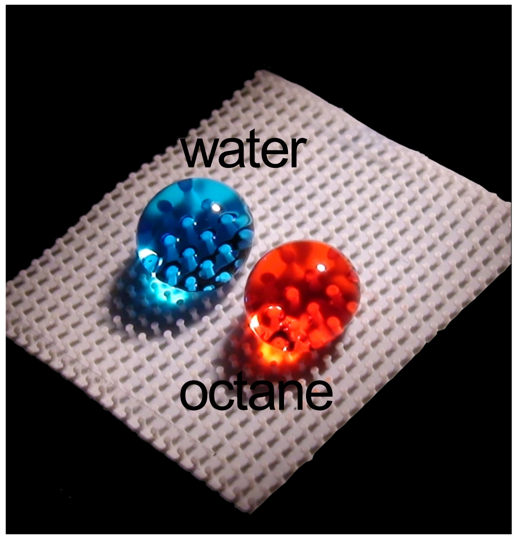
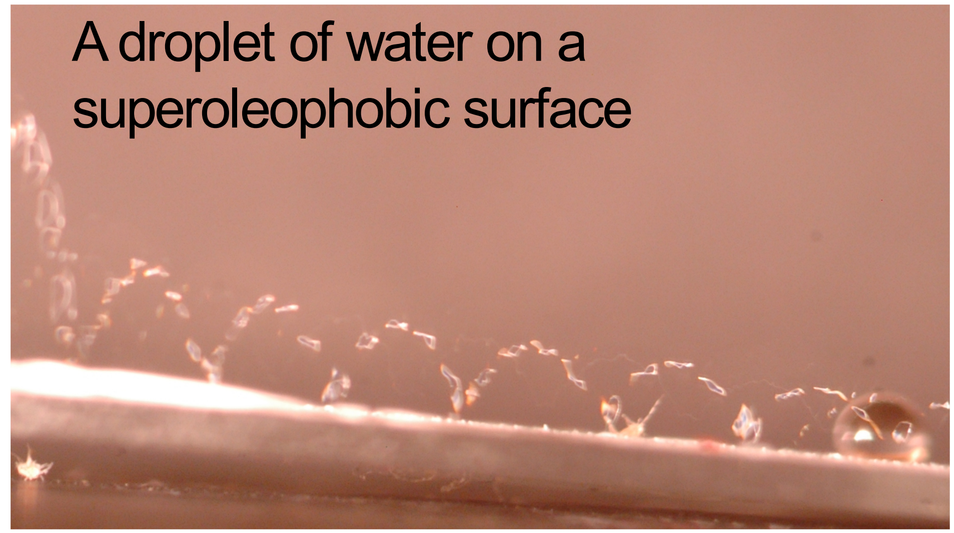
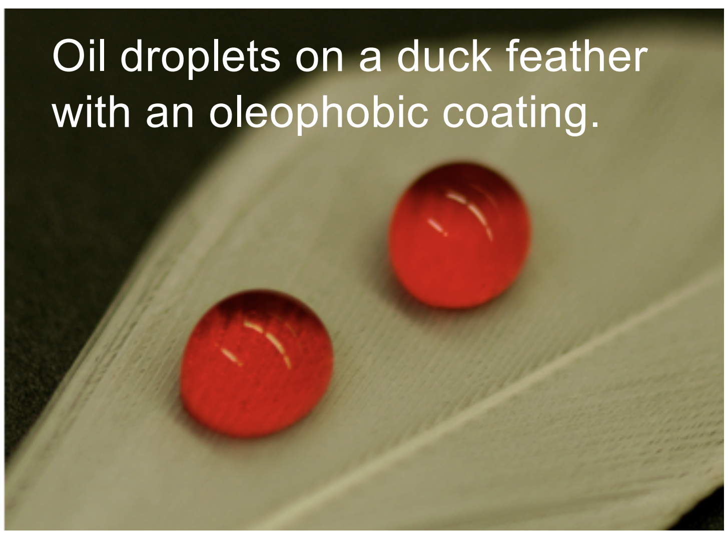
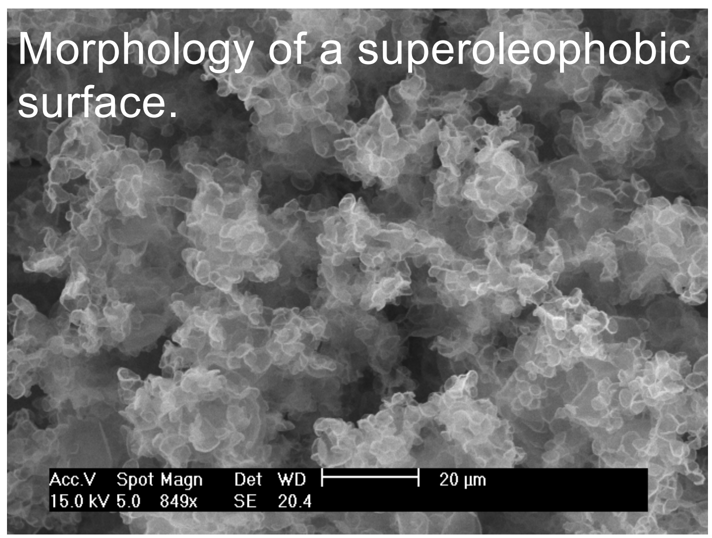
Superoleophobic Surfaces: Surfaces on which all liquids, including water, oils, alcohols, acids and bases bead up and roll-off the surface. Applications include chemical and biological protection, fingerprint resistance, stain-resistant textiles, drag-reduction, preventing biofouling, icephobicity.





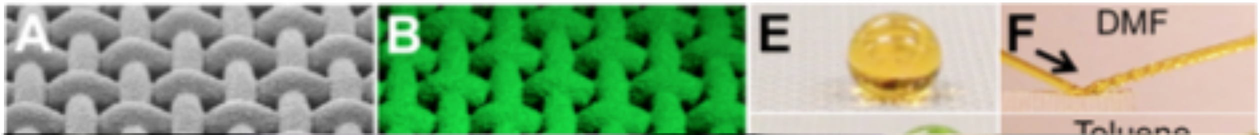






Tuteja *et al.*, *Science*, 2007
Tuteja *et al.*, *PNAS*, 2008
Kota *et al.*, *Advanced Materials*, 2012

Superoleophobic surfaces



In collaboration with Dr. Joe Mabry, Tech Advisor, Propellants branch, Edwards AFB

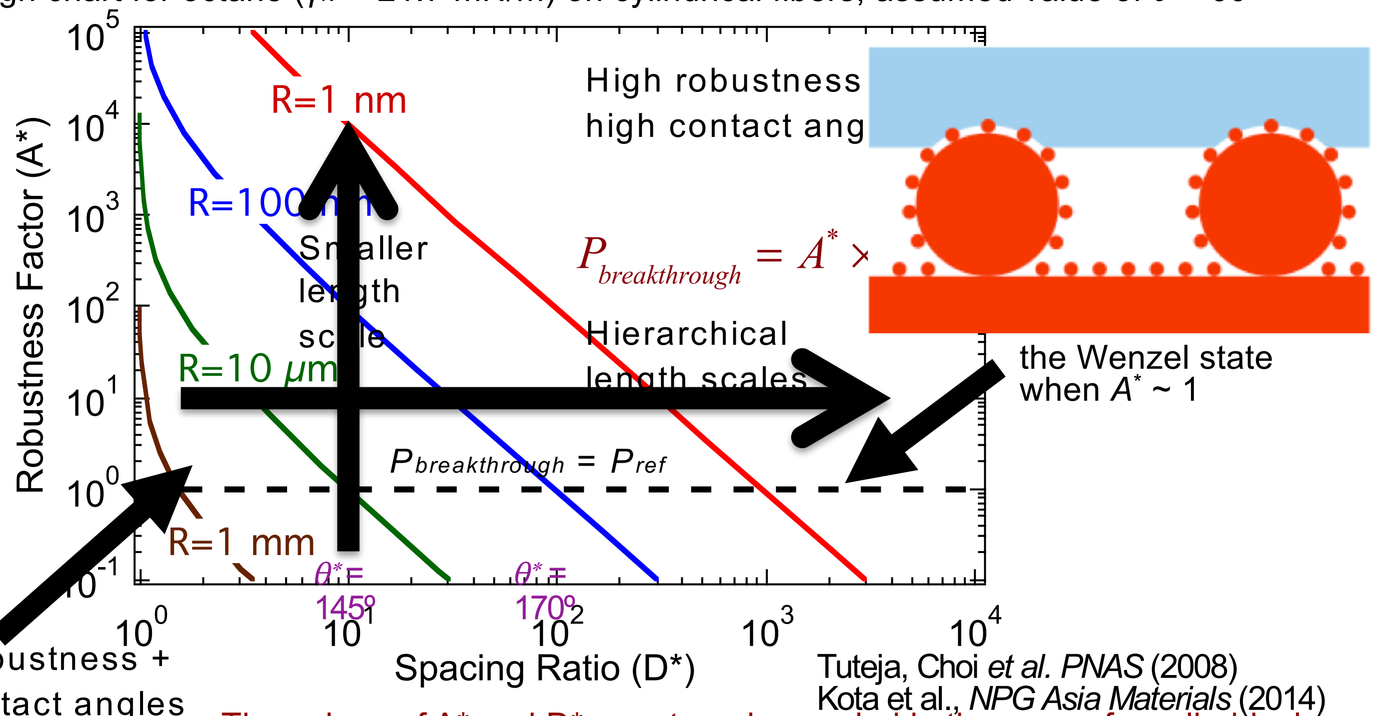
Kota *et al., Advanced Materials*, 2012 ; Pan *et al.*, *JACS*, 2013.

A design chart for a composite interface

$D^* = (R+D)/R$ $\quad A^* = \left(\frac{R\ell_{cap}}{D^2}\right)\frac{(1-\cos\theta)}{(1+2(R/D)\sin\theta)}$

Green: Surface properties
Red: Fluid properties
Blue: Surface-fluid-vapor interaction

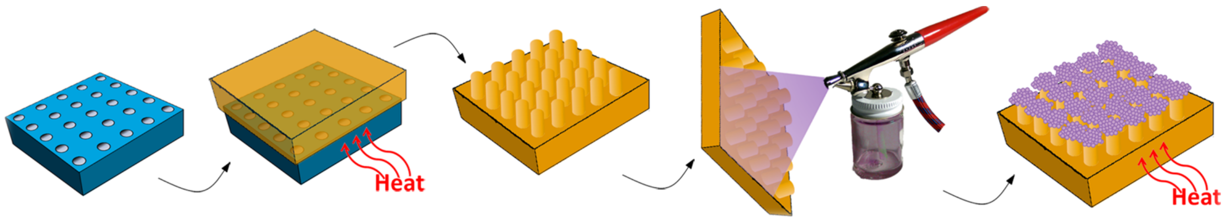
Design chart for octane (γ_{lv} = 21.7 mN/m) on cylindrical fibers; assumed value of θ = 60˚

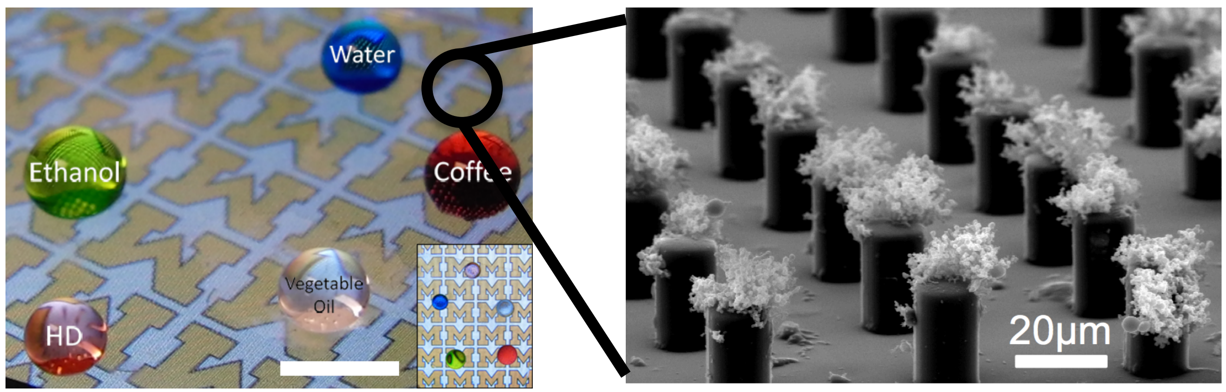


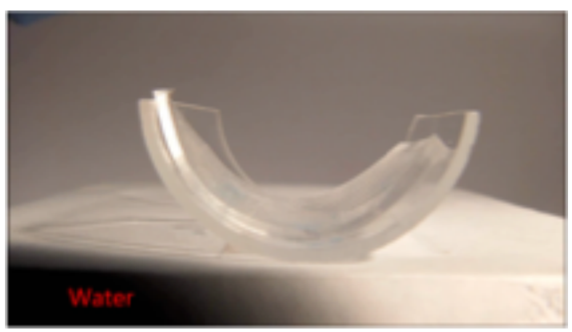
Tuteja, Choi *et al. PNAS* (2008)
Kota et al., *NPG Asia Materials* (2014)

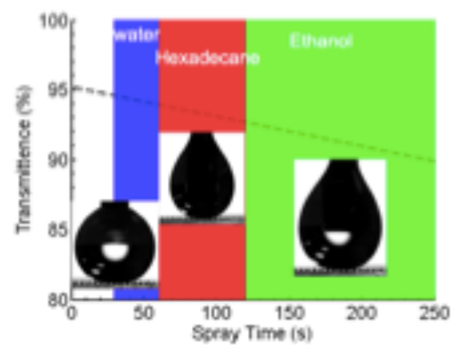
The values of A* and D* are strongly coupled in the case of a cylindrical geometry. Typically an increase in D* will lead to a decrease in A*.

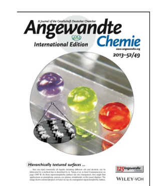
Transparent omniphobic surfaces







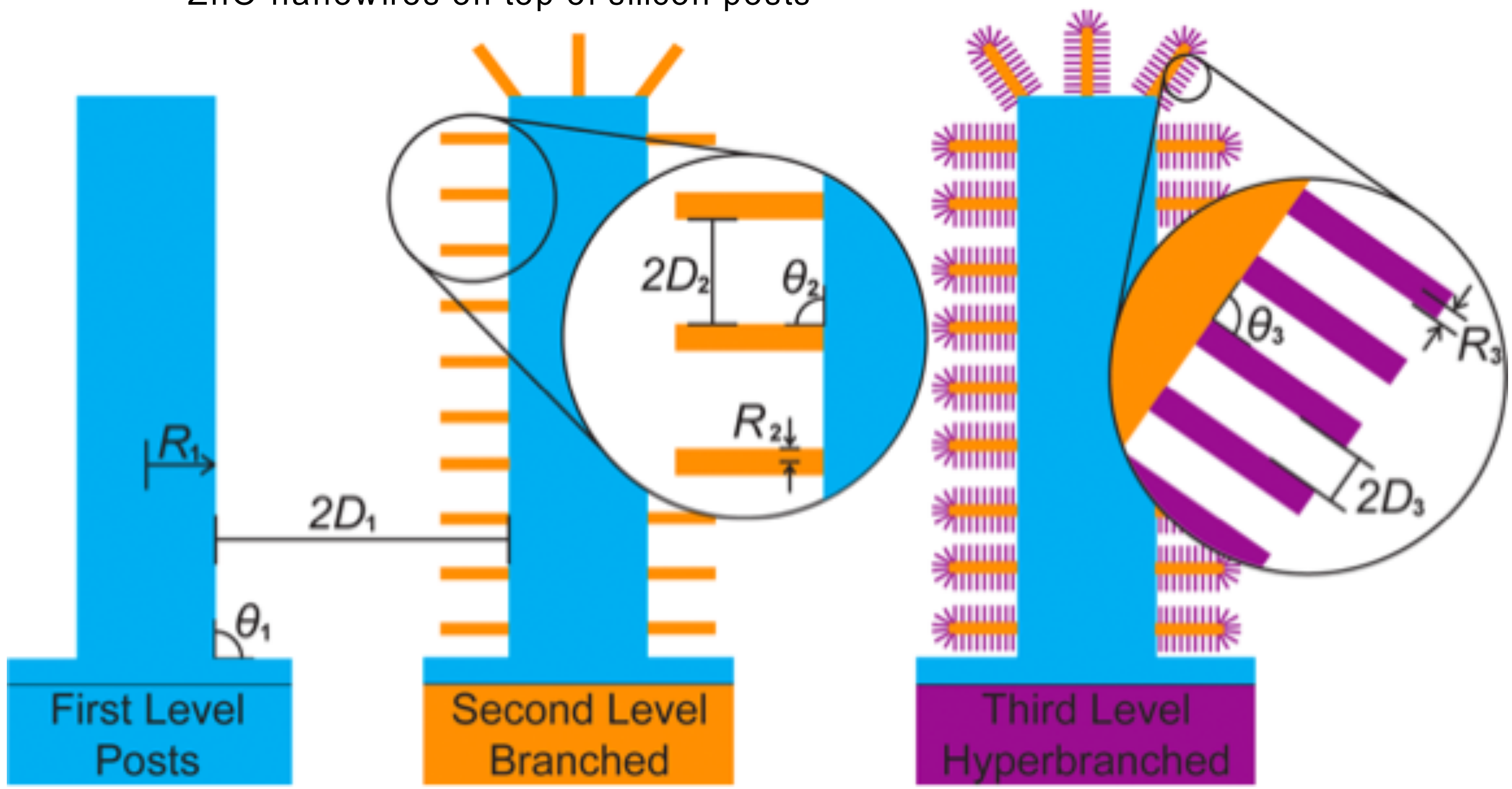




Golovin *et al.*, *Angewandte Chemie*, 2013

Three levels of hierarchical texture

ZnO nanowires on top of silicon posts

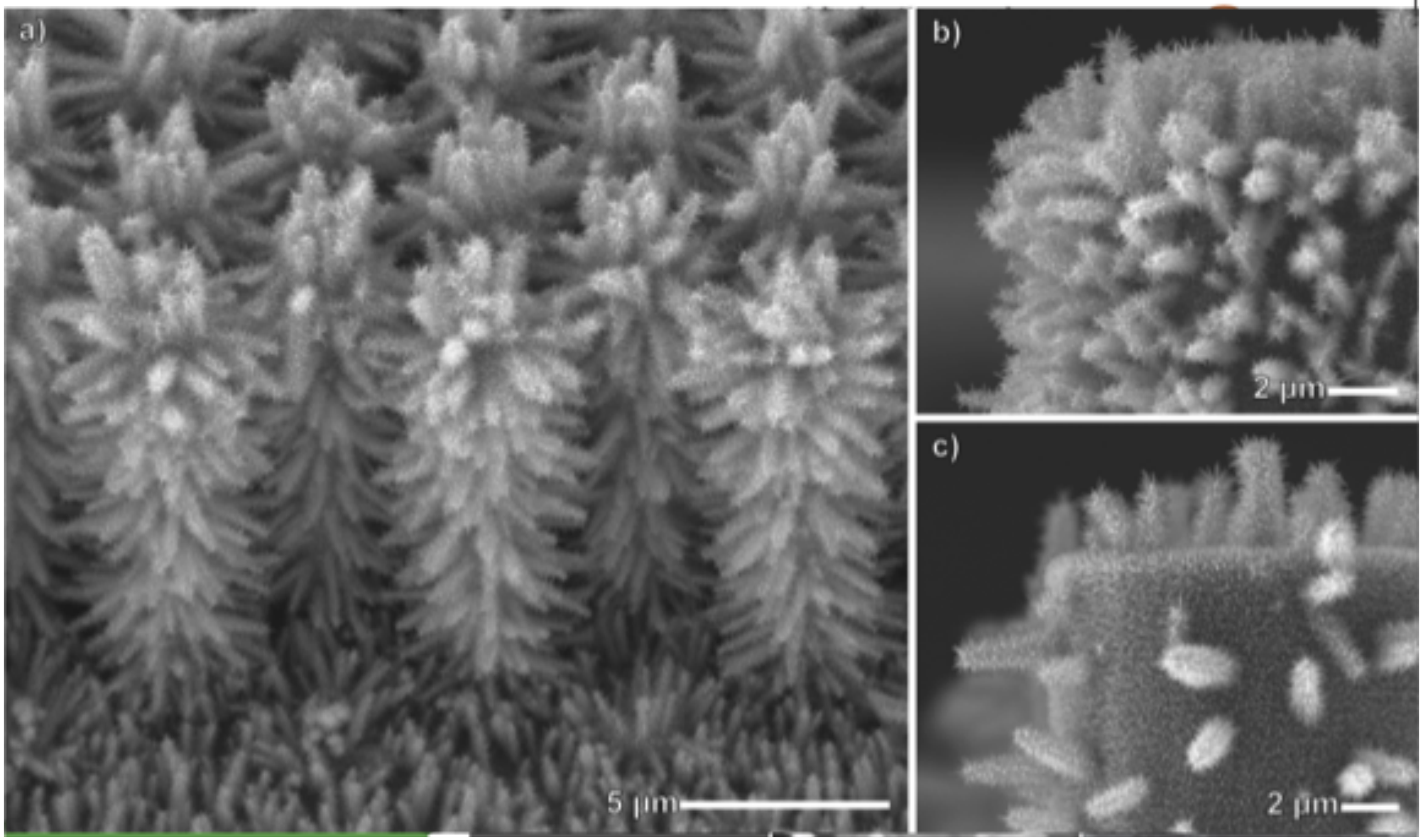


With Neil Dasgupta, Univ. of Michigan

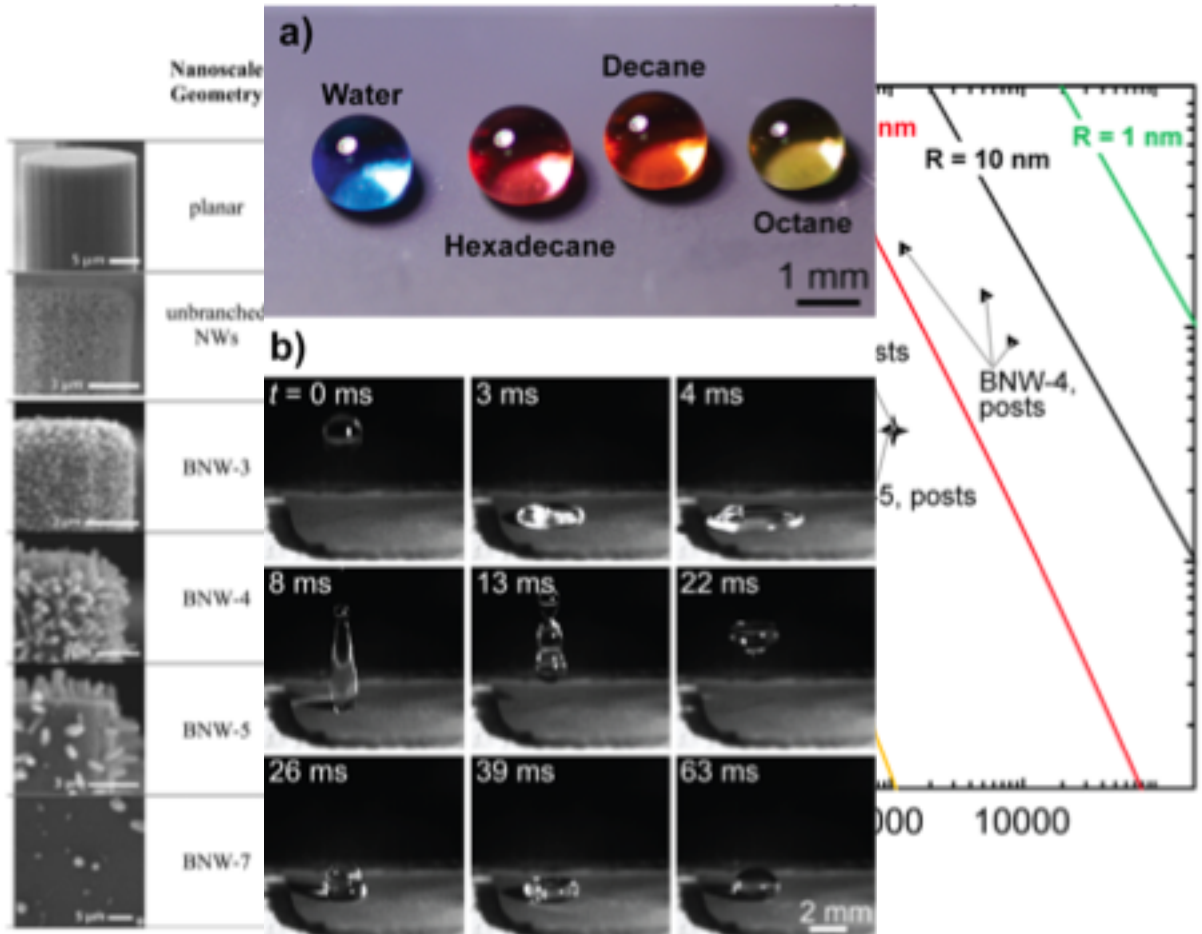
Bielinski *et al.*,
ACS Nano, 2016

ZnO nanowires

a) Low density nanowire growth

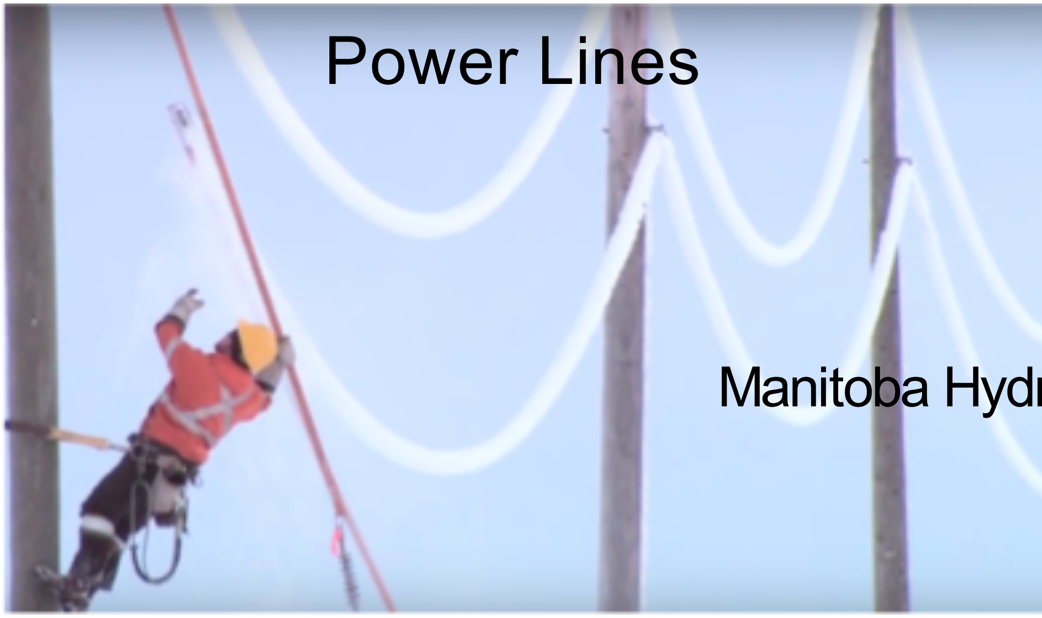


Effects on liquids repellency and robustness



Bielinski *et al.*, *ACS Nano*, 2016

The need for ice-shedding surfaces



The need for ice-shedding surfaces

There is a critical need to develop ice-resistant or ice-phobic coatings for a range of applications. Applications include coatings for automobiles, naval vehicles, aircrafts, wind turbines, refrigeration, power-lines, satellite dishes, off-shore oil drilling platforms. Market size exceeds $5 Bn / year within North America.

Ice-adhesion strength τ_{ice}< 10 kPa required for airplane wings, power lines and wind turbines.

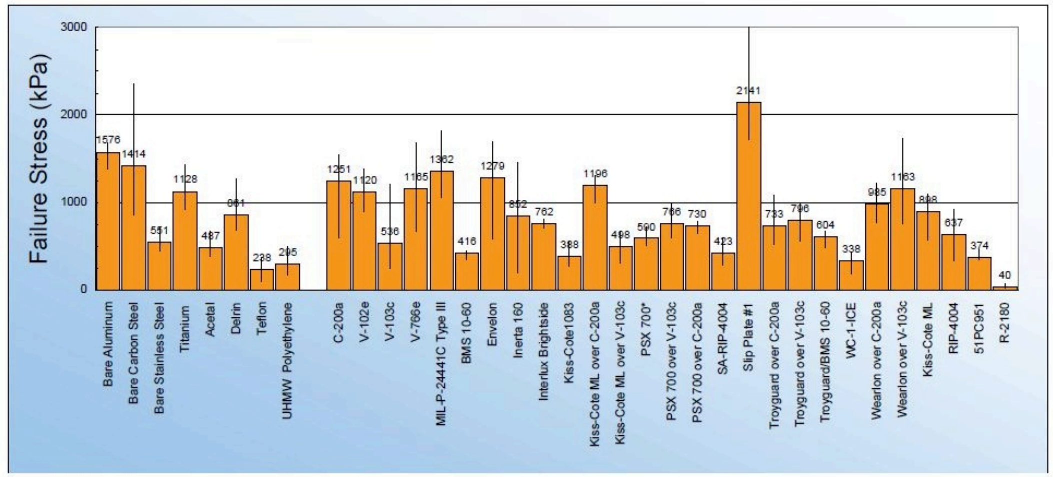


Figure 20-14 Ice adhesion test results for construction materials and commercial coatings. Column heights represent average ice adhesion strength, which is also given as a numerical value on the top of each column. Error bars represent the range in the data.

Source: CRREL

Ice adhesion strengths vary between 40 kPa – 2200 kPa for different materials.

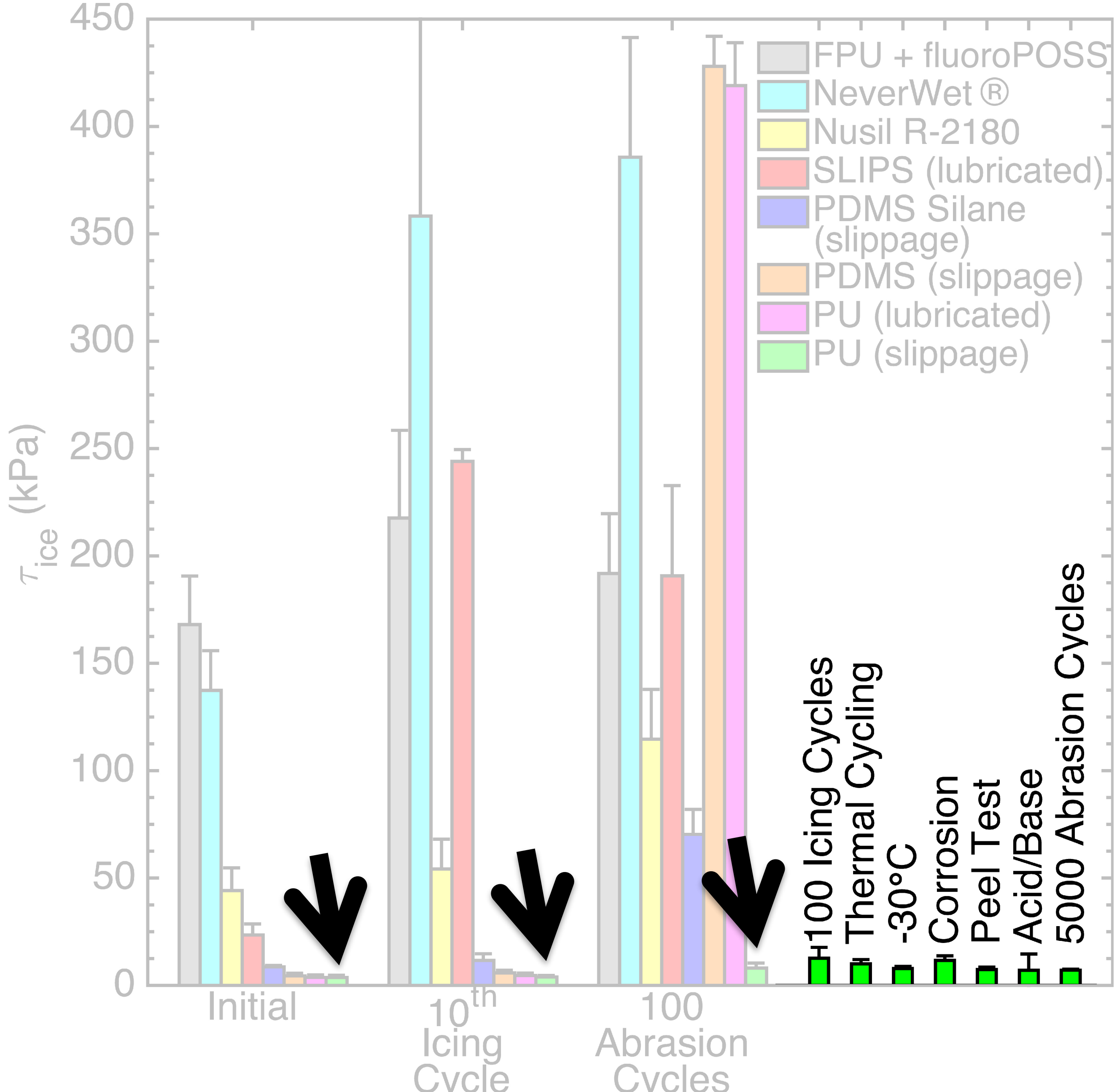
Aluminum: 1600 kPa; Steel: 1400 kPa; Polyethylene: 300 kPa, Teflon: 240 kPa.

Outline

Two Major Challenges for Ice-Shedding Surfaces

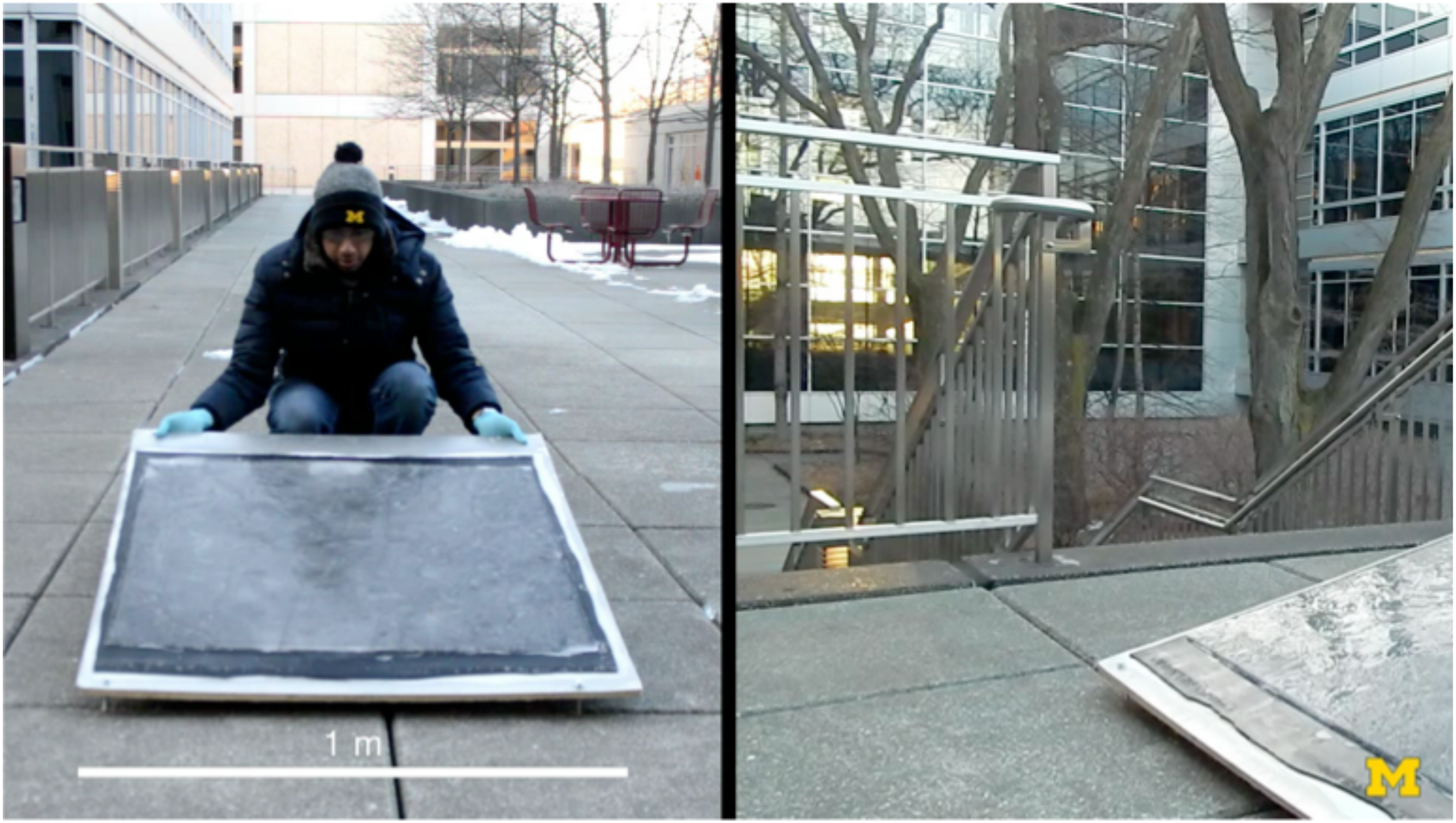
- **Durability**
  - Durable elastomeric icephobic surfaces based on interfacial slippage
    Science Advances, 11 Mar 2016, Vol. 2, no. 3, e1501496
  - A predictive framework for the design and fabrication of icephobic polymers
    Science Advances, 22 Sep 2017, Vol. 3, no. 9, e1701617
- **Scalability**
  - Promoting crack propagation
  - Low Interfacial Toughness Materials
    Science, 26 Apr 2019, Vol. 364, Issue 6438, pp. 371-375

Durable Icephobic Surfaces



Golovin *et al. Sci. Adv.* **2**, e1501496 (2016)

Large Scale 2D Testing

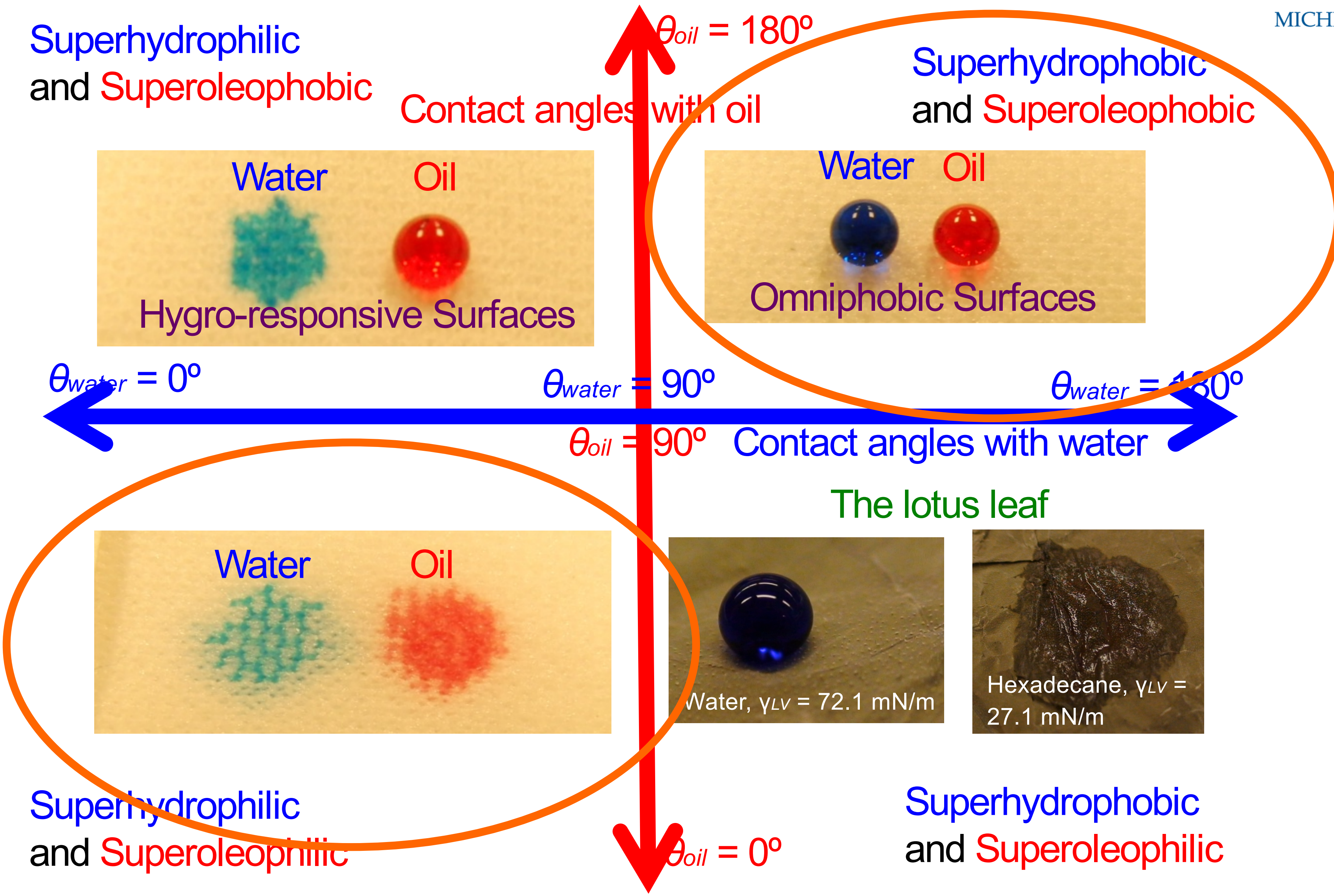


τ_{ice} = **0.07 kPa!**

T = -6ºC

Science, 26 Apr 2019, Vol. 364, Issue 6438, pp. 371-375

The wettability landscape



Patterned superoleophobic / superoleophilic surfaces

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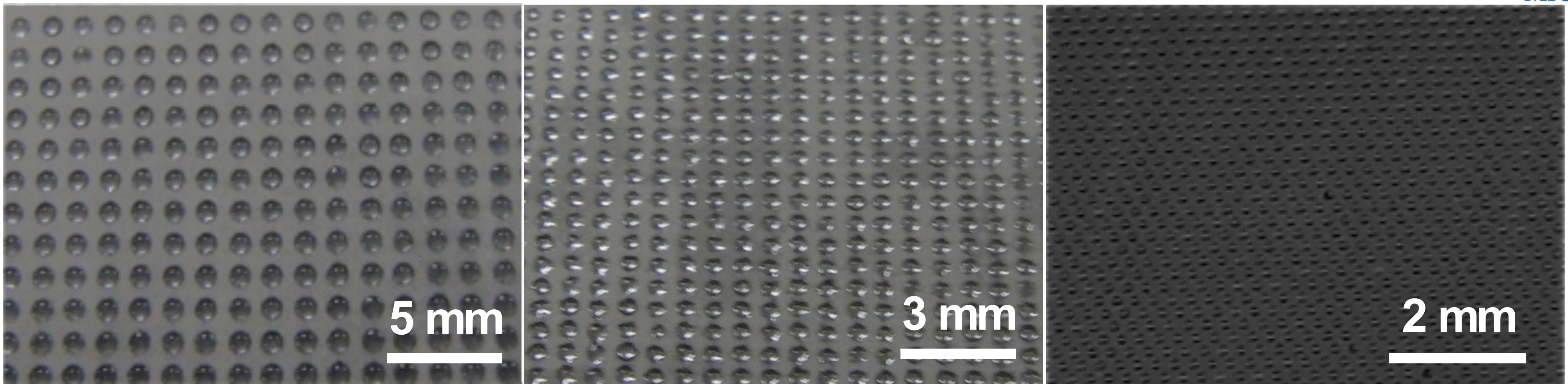

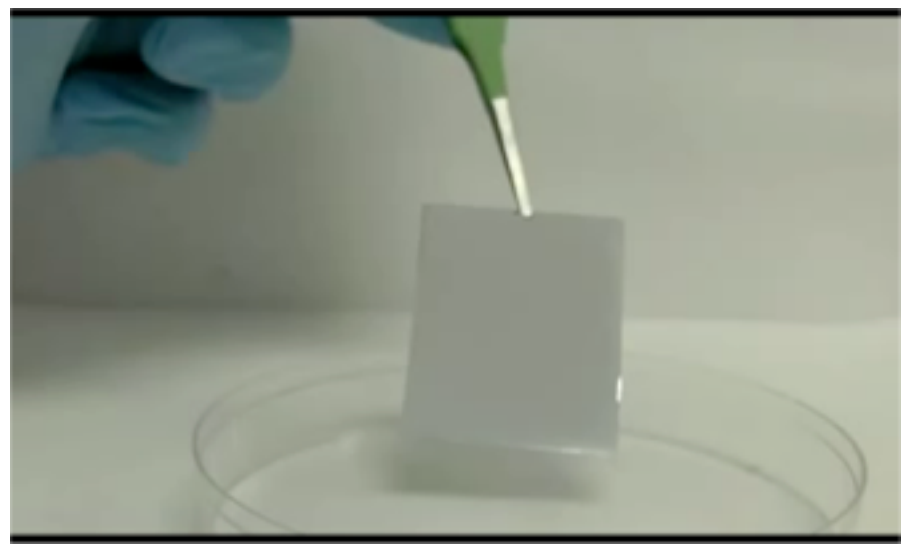

We have developed the first-ever patterned superoleophobic – superoleophilic surfaces. Superoleophilic surfaces are essentially wet by all liquids, while superoleophobic surfaces repel all liquids.

Kobaku *et al. Angewandte Chemie*, 2012

Fabrication of mono-,bi-, tri- and multi-phasic particles

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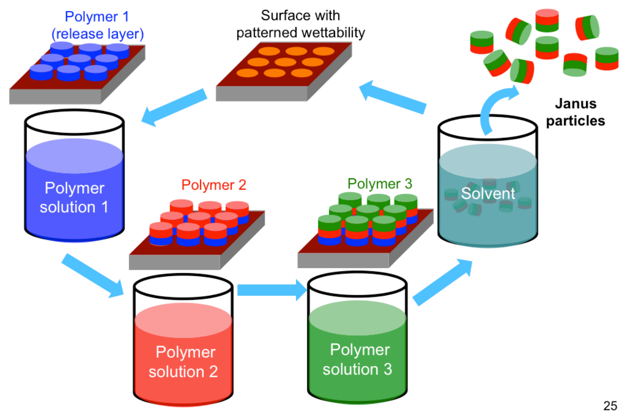
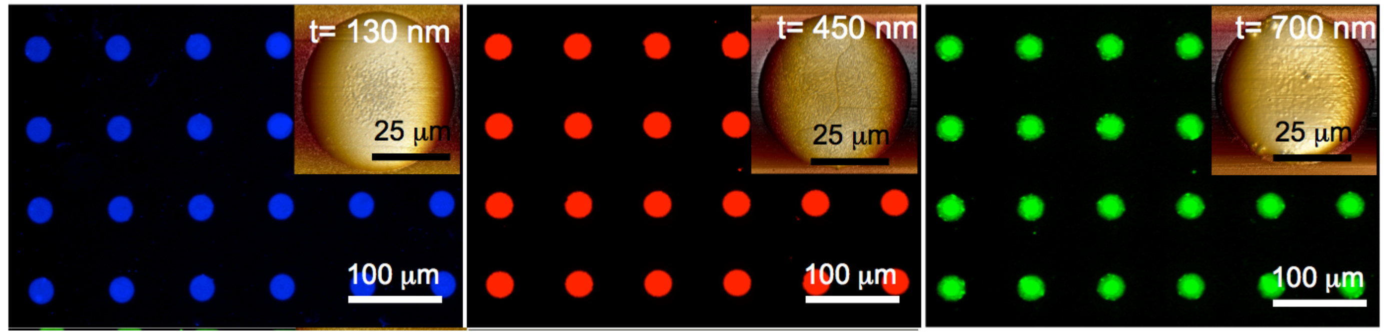
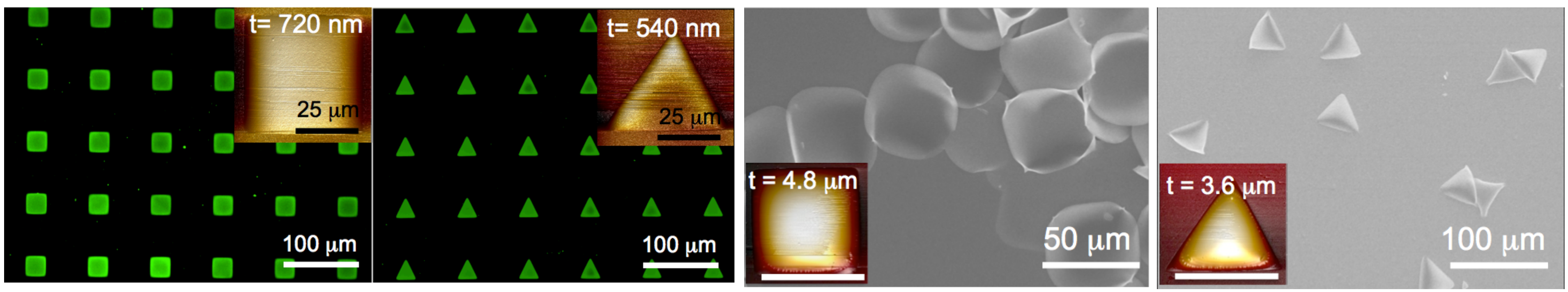
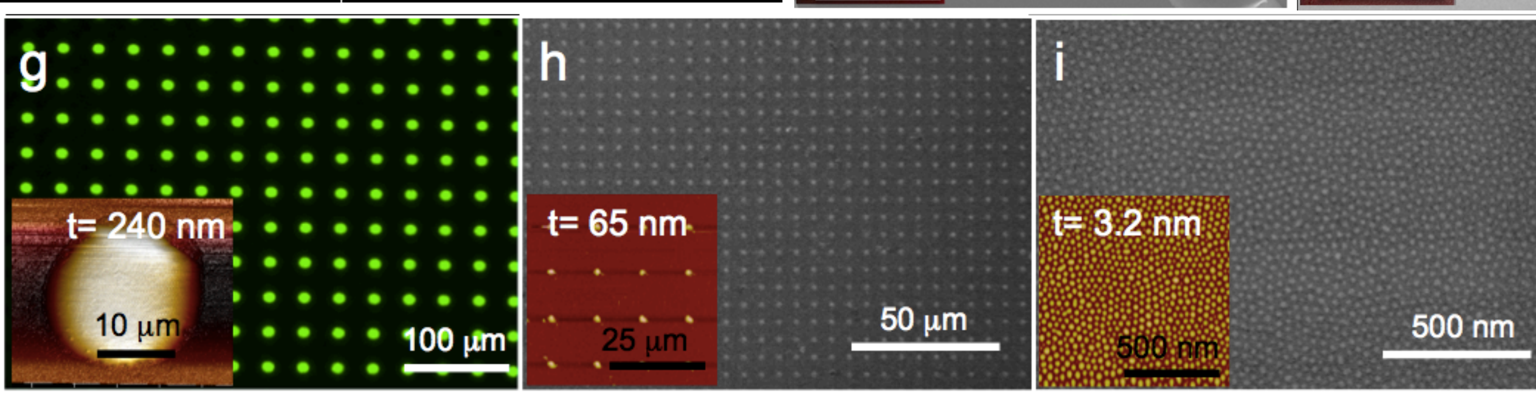


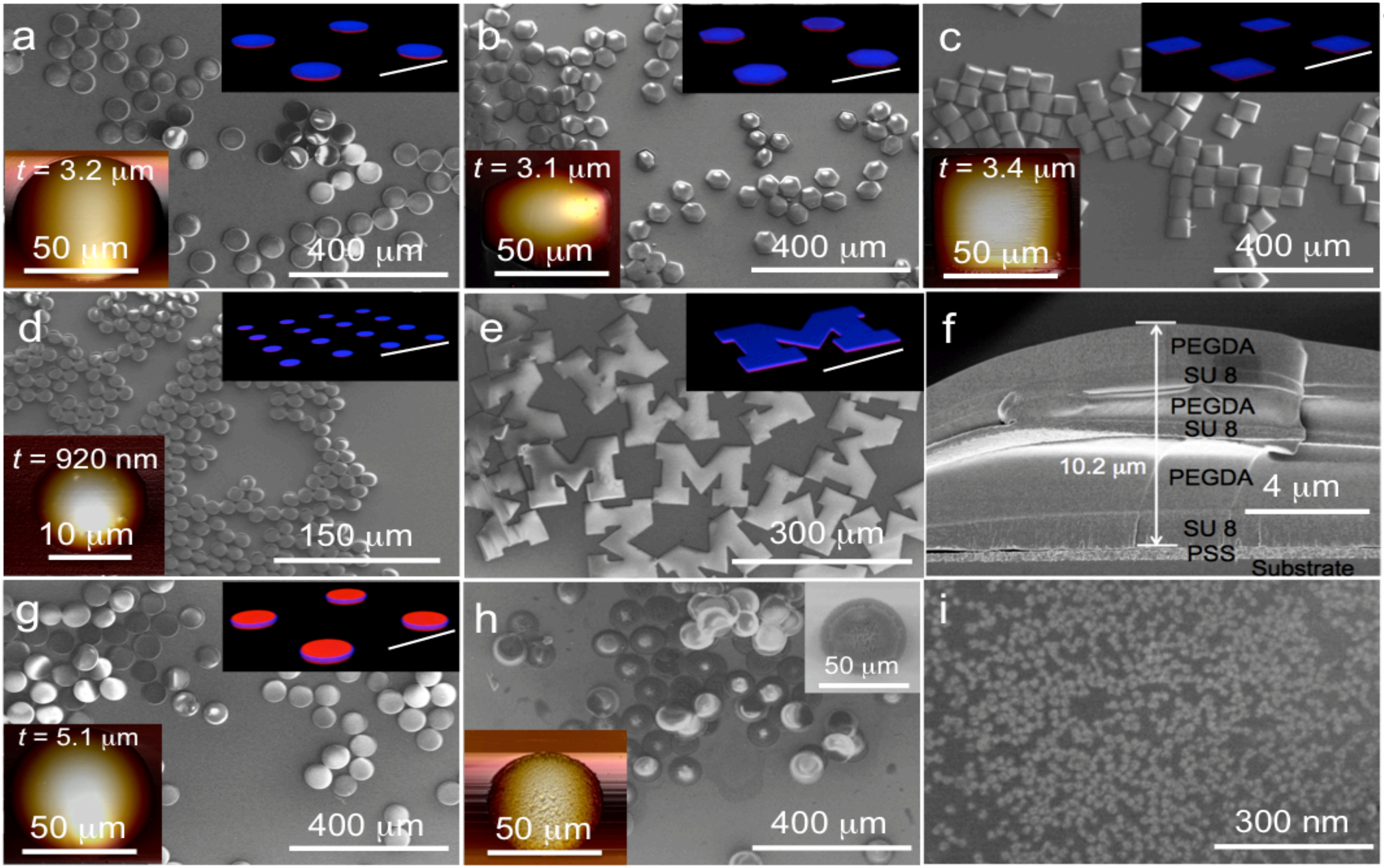






Unprecedented ability to manufacture on a large scale particles of any size, shape or chemistry. Particle shape and size can be used to engineer bio-distribution, skin or lung uptake, intra-cellular localization and cell response.

Multi-phasic particles



Kobaku *et al.*, *ACS Appl. Mater. Interfaces*, **2015**, *7* (7), pp 4075–4080

Shape shifting to create spherical particles

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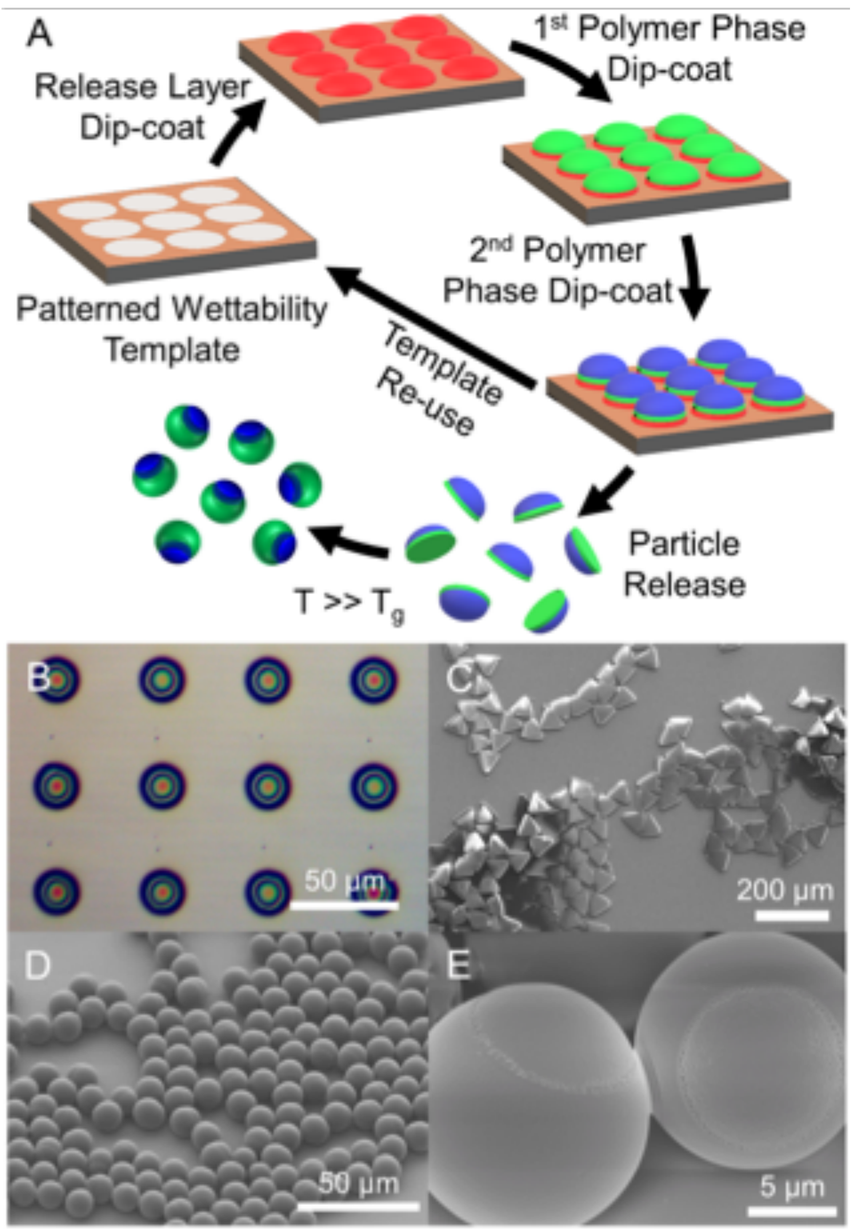
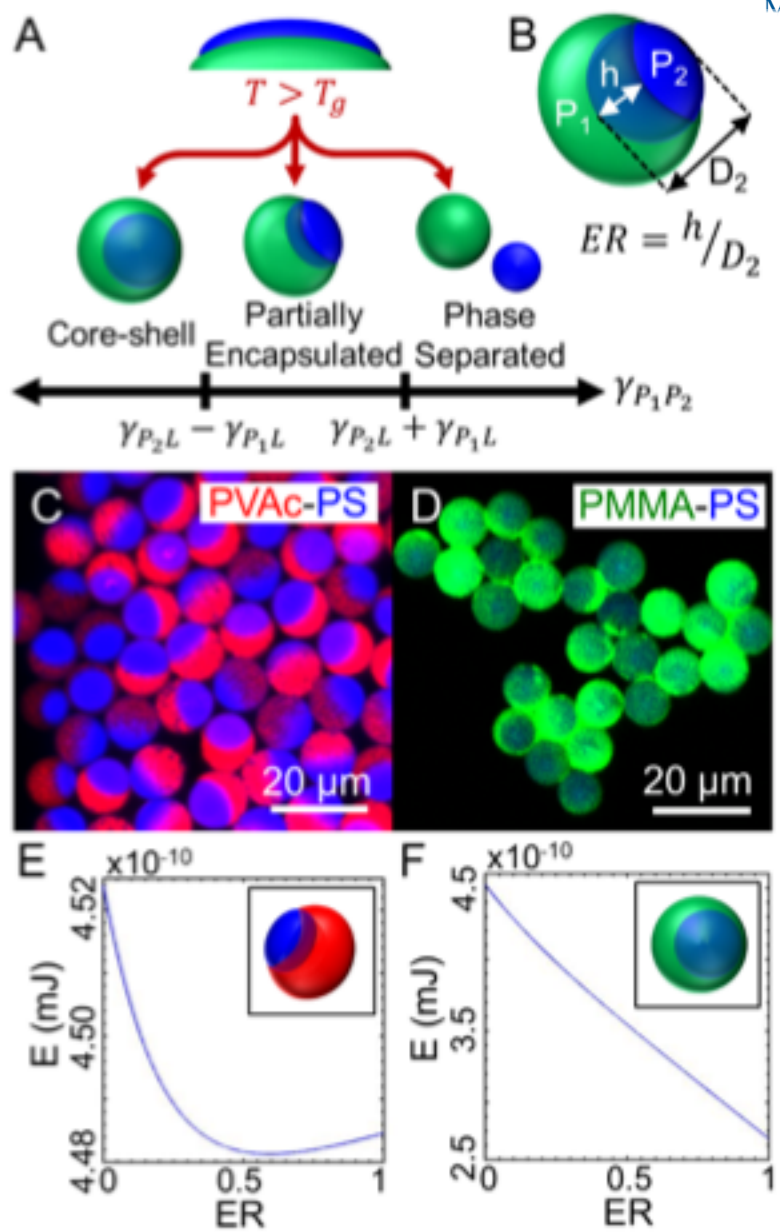
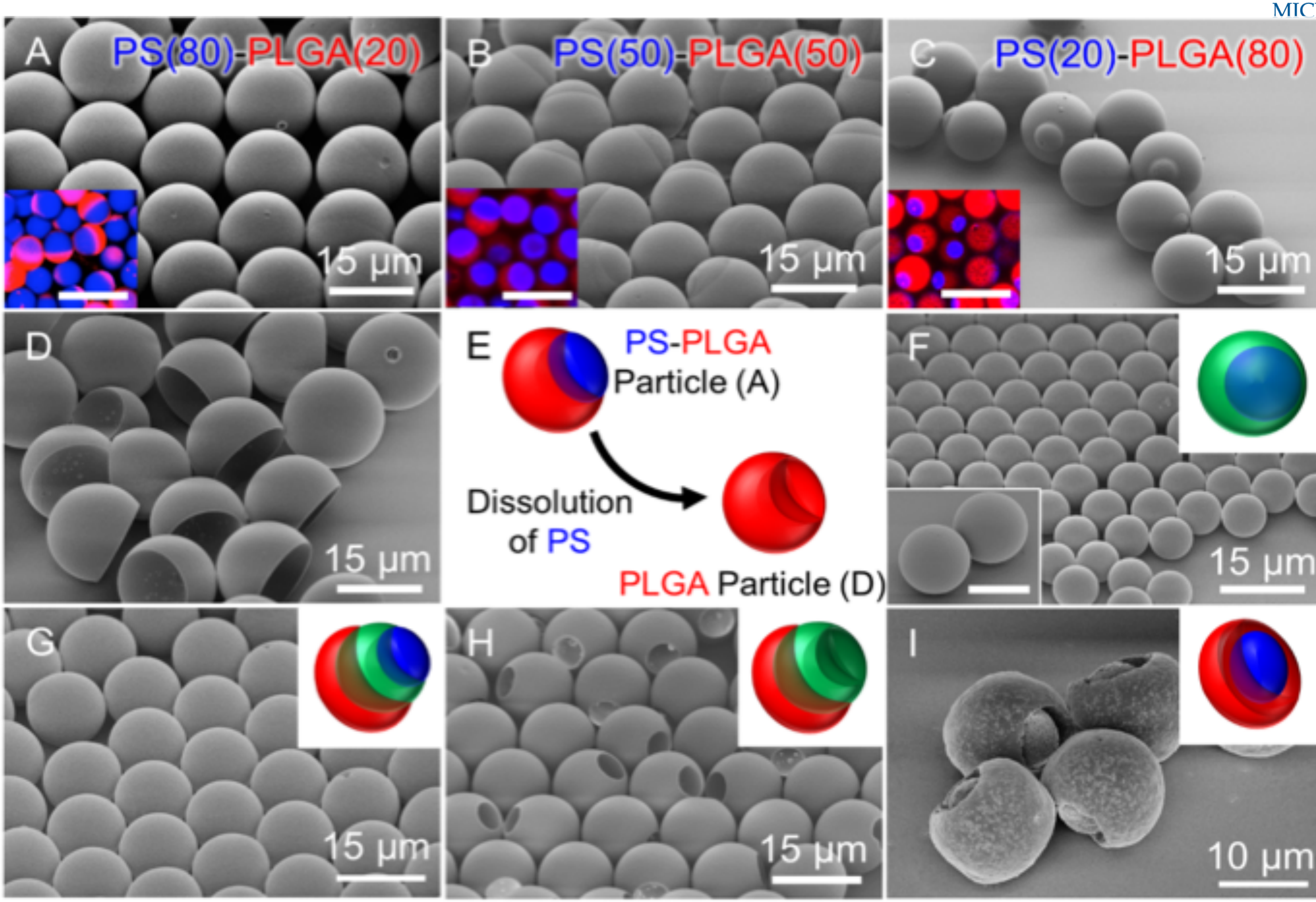




Shape shifting to create spherical particles



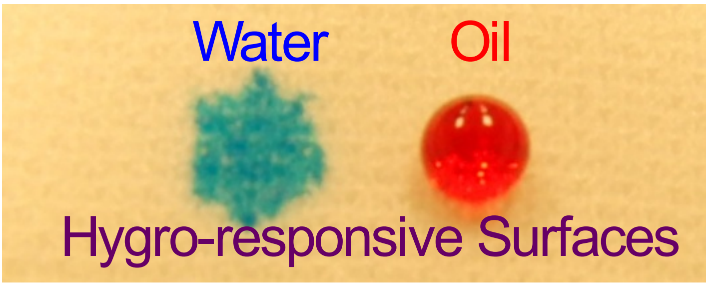
The wettability landscape

Superhydrophilic
and Superoleophobic

Contact angles with oil

θ_{oil} = 180º

Superhydrophobic
and Superoleophobic



θ_{water} = 0º

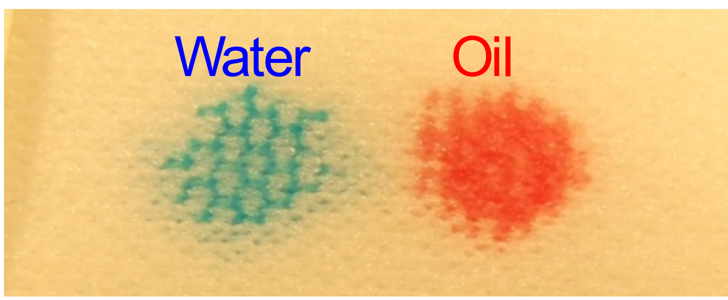
θ_{water} = 90º

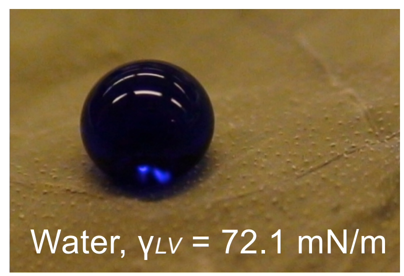
θ_{water} = 180º

θ_{oil} = 90º

Contact angles with water

The lotus leaf





Superhydrophilic
and Superoleophilic

θ_{oil} = 0º

Superhydrophobic
and Superoleophilic

Membranes for oil-water separation

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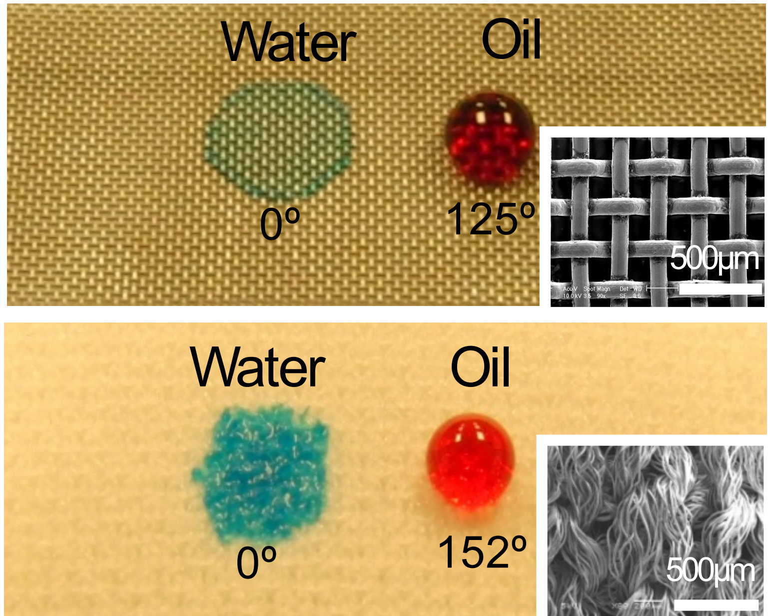
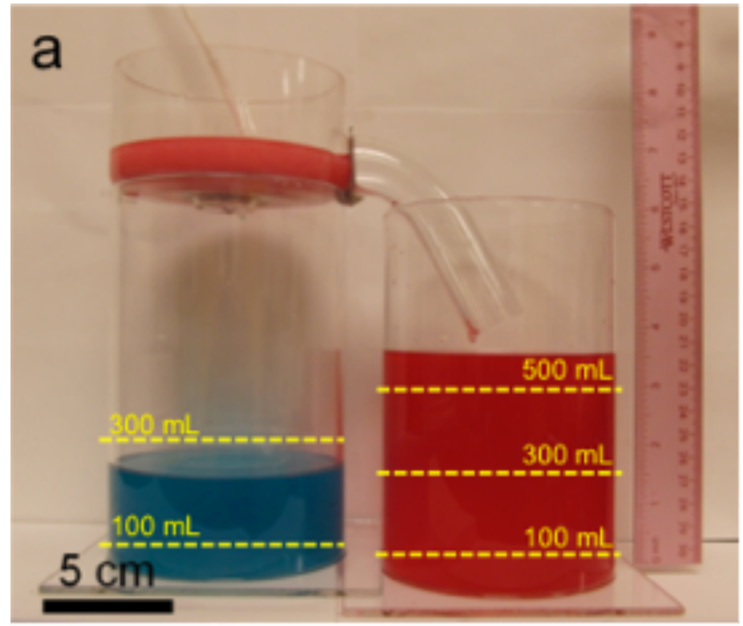


Developed one of the first coatings that counter-intuitively are hydrophilic and oleophobic.

Membranes based on these coatings can allow, for the first time, for the gravity based separation of all kinds of oil-water mixtures.

Applications include clean up of oil-spills, waste-water treatment, emulsion break-up, and oil-extraction.



This is the first-ever setup developed for the continuous separation of oil-water emulsions which utilizes only gravity. The membrane separation efficiency exceeds 99.99%.

Kota *et al. Nature Communications*, 2012
Kwon *et al. Advanced Materials*, 2012

In collaboration with Dr. Joe Mabry, Tech Advisor, Propellants branch, Edwards AFB

Membranes for oil-water separation

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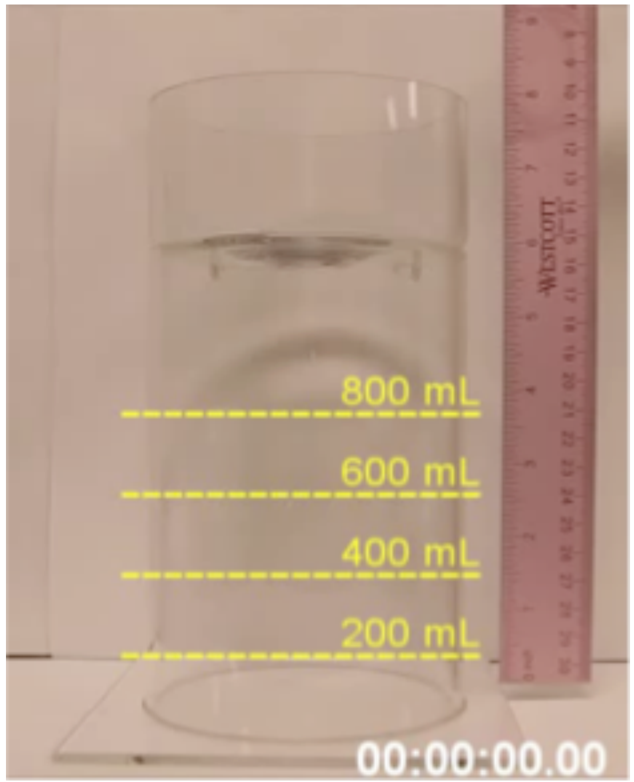
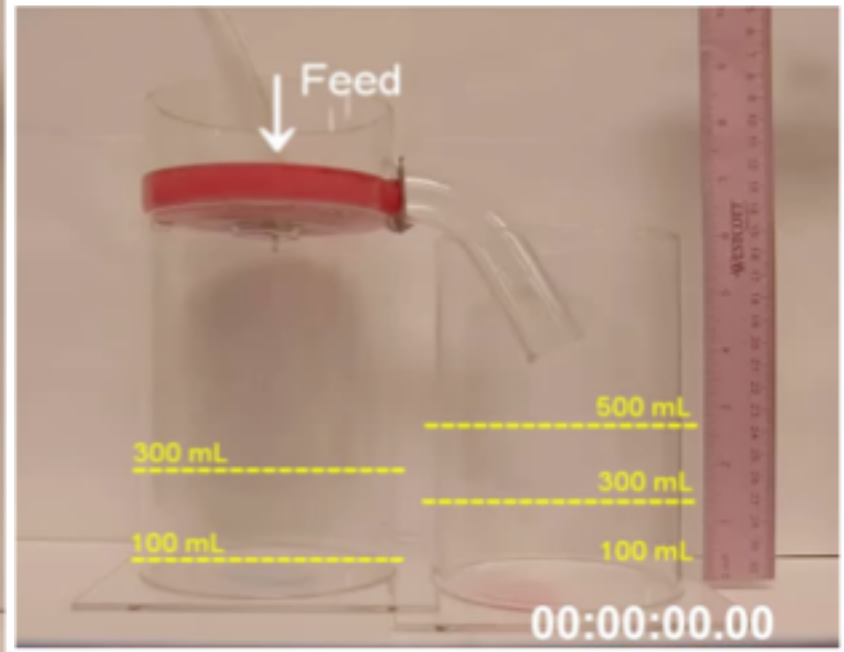
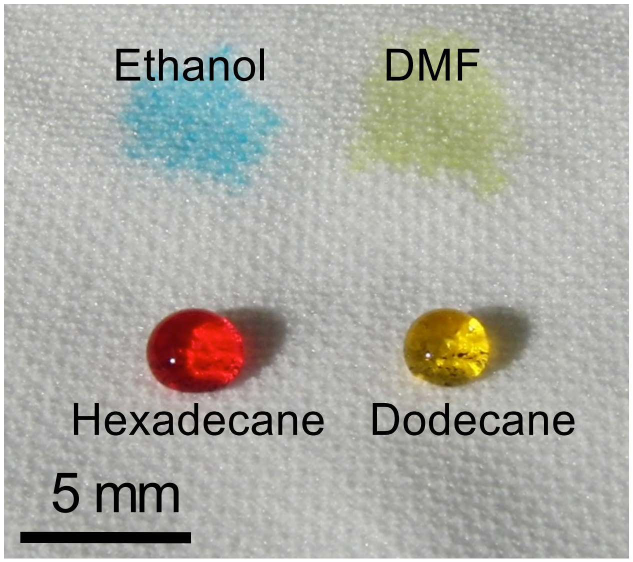




Kota *et al. Nature Communications*, 2012

Liquid-liquid extraction



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Contact information:

Email: atuteja@umich.edu; Ph. 734-615-2972

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