IWAIS2015

16TH INTERNATIONAL WORKSHOP ON ATMOSPHERIC ICING OF STRUCTURES

Supercooled Water Wettability and Freezing on Hydrophobic Surfaces: The Role of Temperature and Topography

KTH-Royal Institute of Technology, Sweden

School of Chemical Science and Engineering

Division of Surface and Corrosion Science

Golrokh Heydari,

Eric Tyrode, Maziar Sedighi, Mikael Järn, Mikko Tuominen, Per M. Claesson

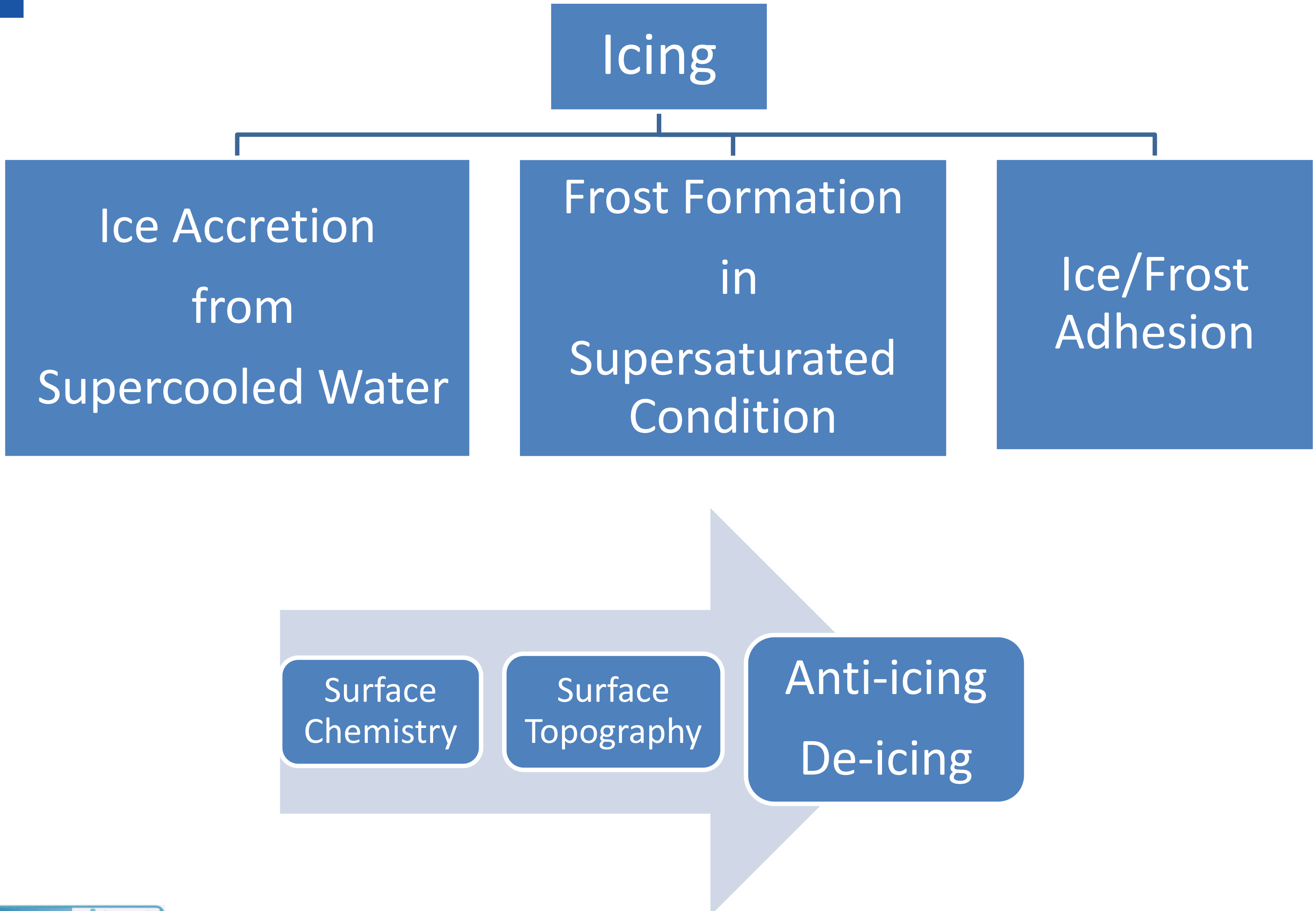
a Nordic research project

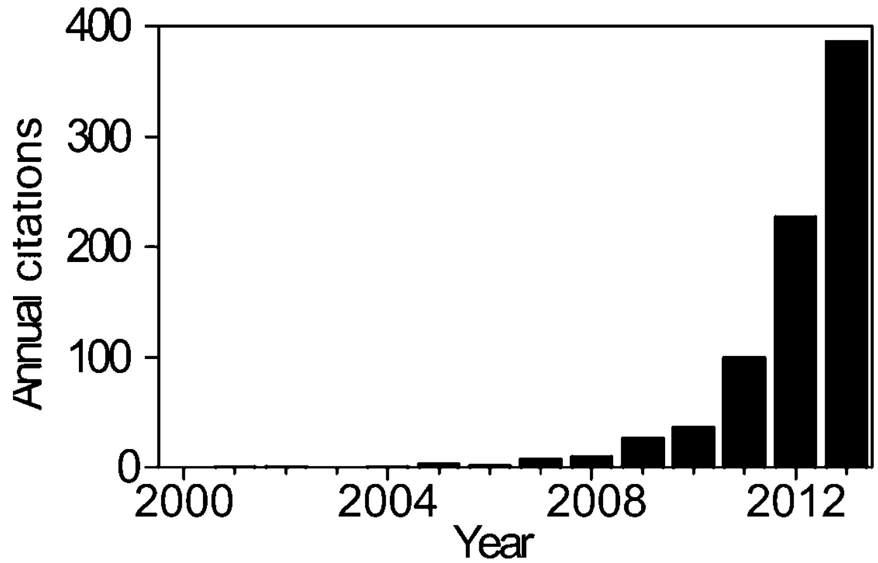
with the aim to develop sustainable and efficient methods based on nanotechnology to reduce problems and costs with ice build-up

support from the Top-level Research Initiative

KTH
SP
VTT
Aarhus University

Advanced Marine Coatings AS
Thermia Heat Pumps
AB Electrolux
Fläkt Woods AB
Gränges
MW Innovation AB
n-TEC AS
Nibe Heating Systems AB
Re-Turn AS
Saab AB
Vattenfall


Icing
Ice Accretion from Supercooled Water
Frost Formation in Supersaturated Condition
Ice/Frost Adhesion
Surface Chemistry
Surface Topography
Anti-icing
De-icing



Schutzius et al., Langmuir 2015, 31, 4807–4821

Discrepancy on research reports on anti-icing and de-icing surfaces:

-Surface material, morphology and architecture and robustness
-Experimental conditions such as temperature, RH, water
-Static or dynamic ice build-up
-heat transfer mechanism
-etc.

Supercooled Water Wetting & Freezing
on
Hydrophobic and Superhydrophobic Surfaces

Focus on:

1. Surface topography

surface material:

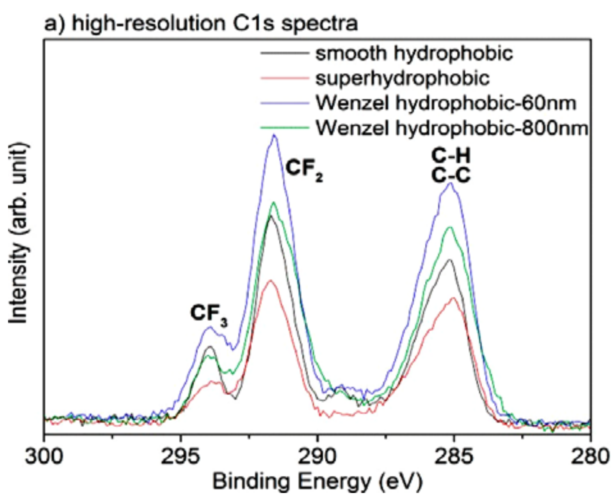
silica+silica nanoparticles+fluoropolymer (similar chemistry)

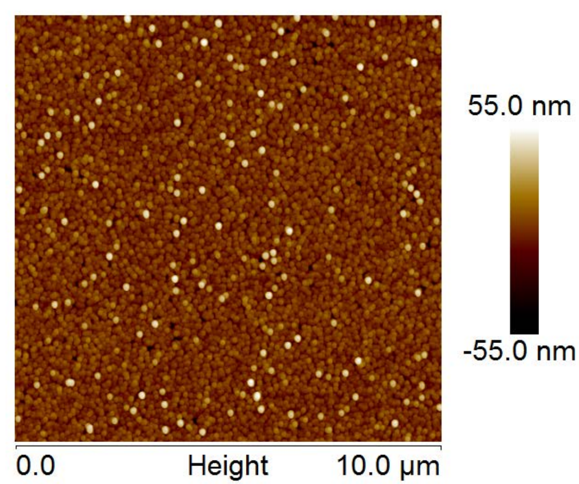
surface topography:

smooth to rough (with RMS between 1 to 250 nm)

wetting state:

hydrophobic to superhydrophobic (contact angle between 100 to 160)



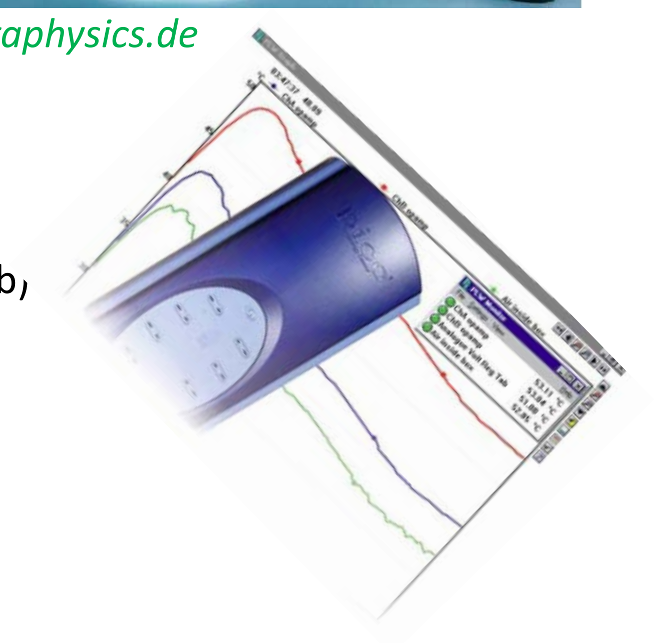


temperature dependent supercooled water-wetting & freezing

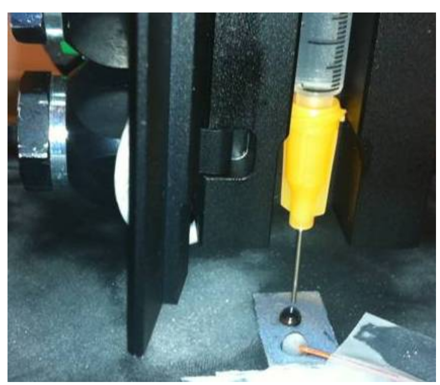
DataPhysics OCA40 micro instrument

- high speed CCD camera (2200 image s^{-1})
- peltier cooling stage
- fast response surface temperature sensor
- high resolution temperature logger

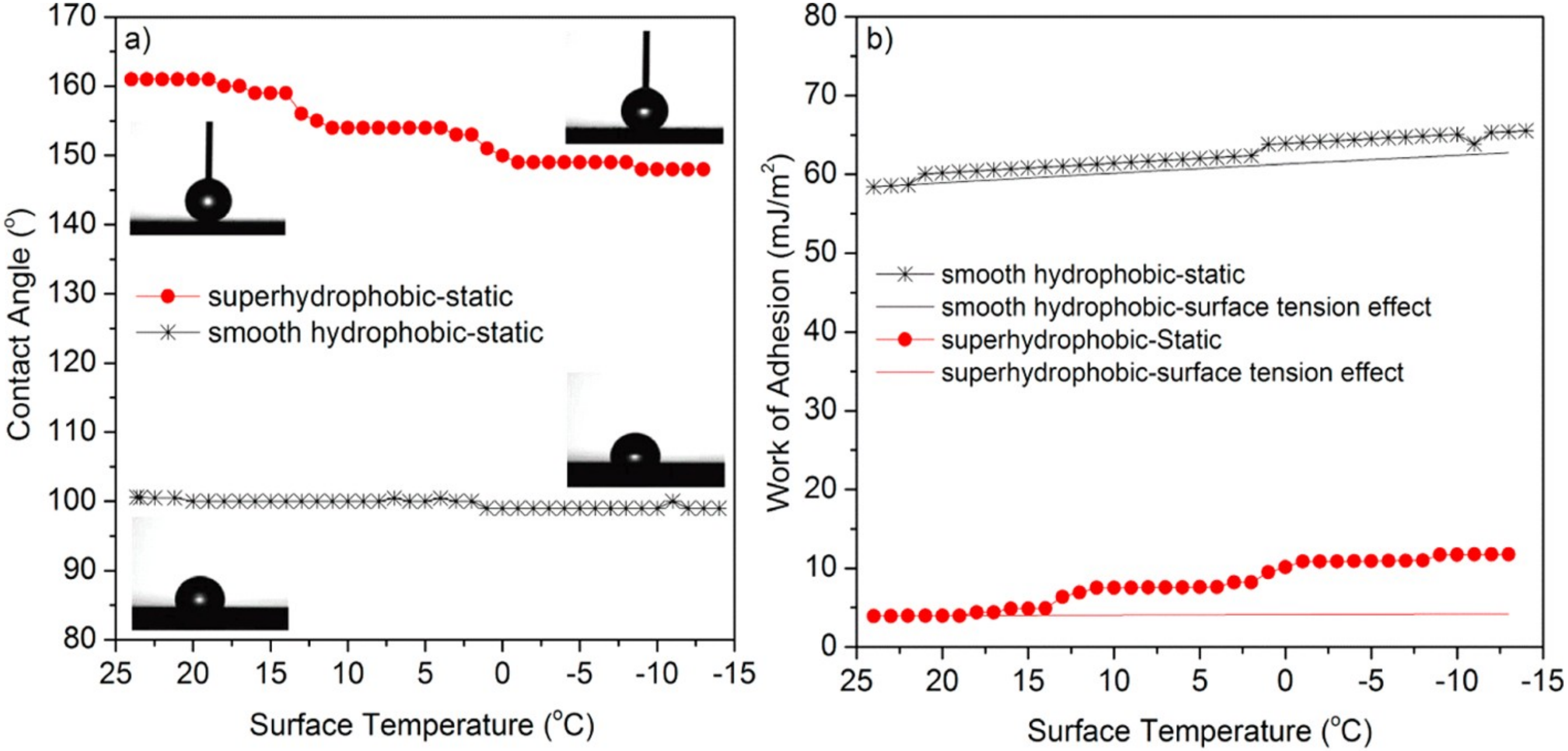
www.dataphysics.de



- controlled climate (relative humidity 40% at 23 °C)
- 4-5 µL sized stationary water droplet
- purified water (resistivity:18.2 MΩcm, organic content < 3 ppb)



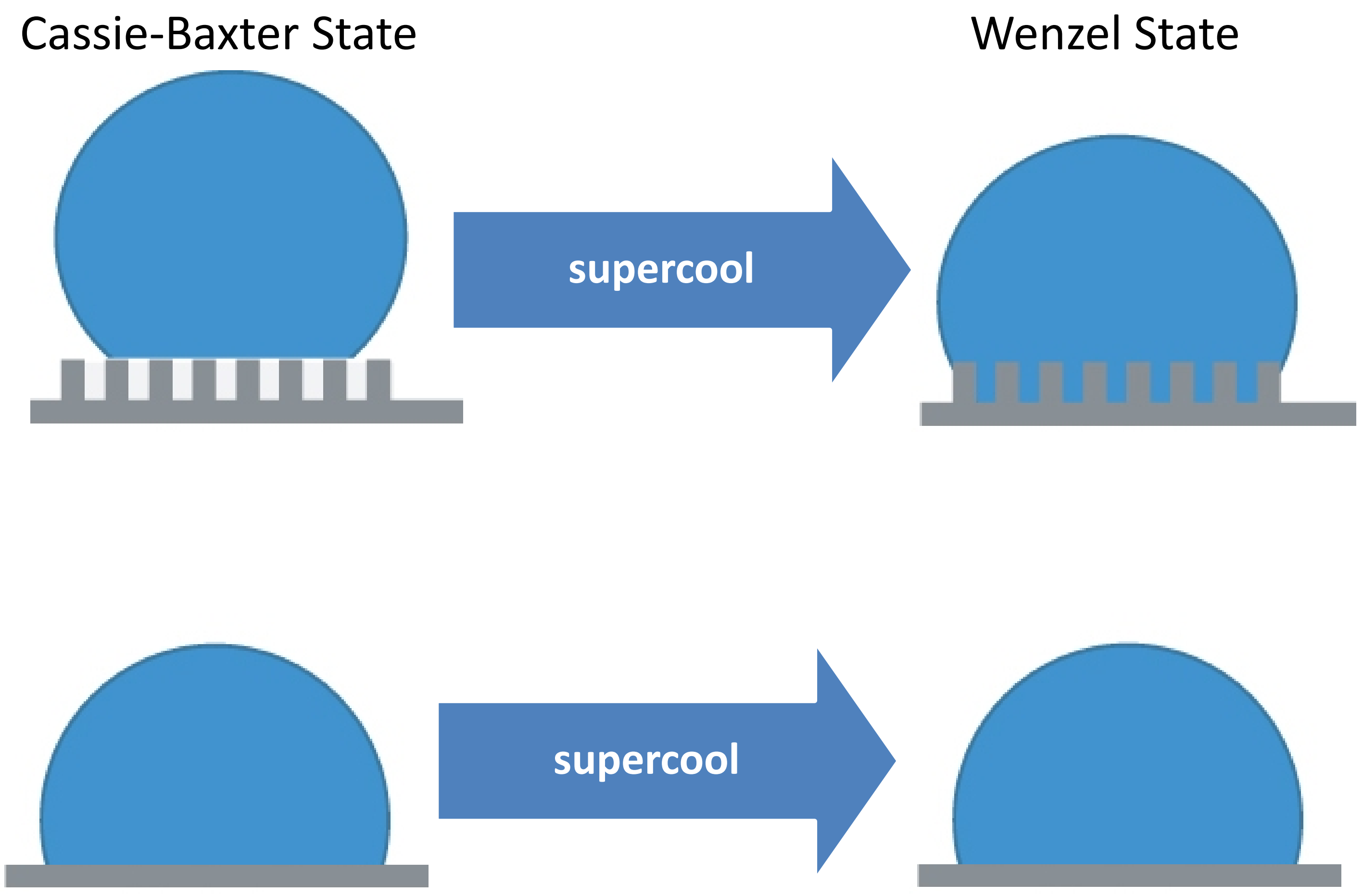
temperature- dependent supercooled water wetting



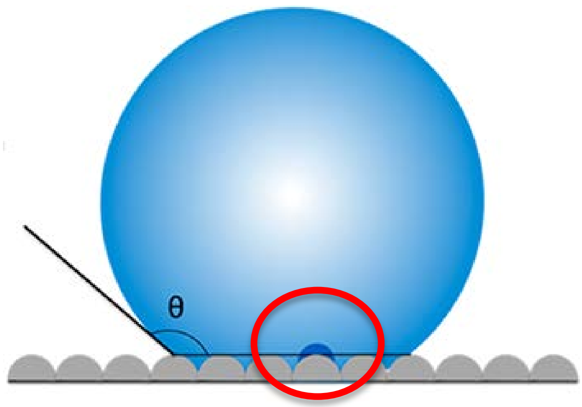
Young-Dupré equation: $W_e = \gamma_{LV}(1+\cos\theta_s)$

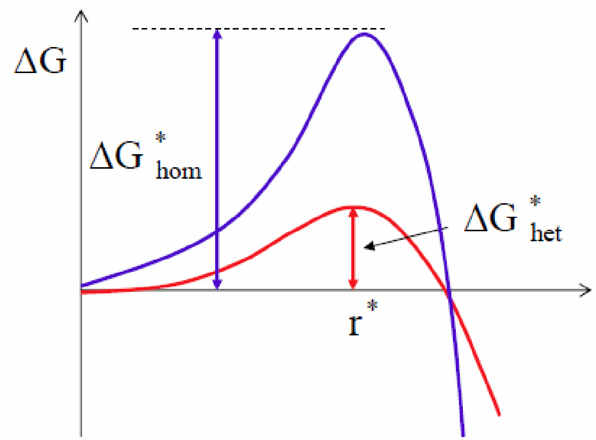
IWAIS2015 16TH INTERNATIONAL WORKSHOP ON ATMOSPHERIC ICING OF STRUCTURES

temperature-dependent wetting hysteresis



heterogeneous nucleation of ice in supercooled water





http://soft-matter.seas.harvard.edu/index.php/Nucleation

ΔG^*: the free energy of formation of a critical ice nucleus on a spherical nucleating particle with radius r

$$\Delta G^* = \frac{8\pi\gamma_{12}^{\ 3}}{3(\Delta G_v)^2} f(m,x)$$

ΔG_v : volumetric free energy difference between the bulk ice nucleus and the bulk supercooled water

γ_{12}: ice-supercooled water interfacial tension

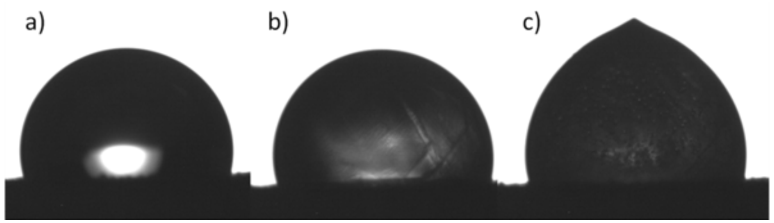
$m = \cos\Theta$

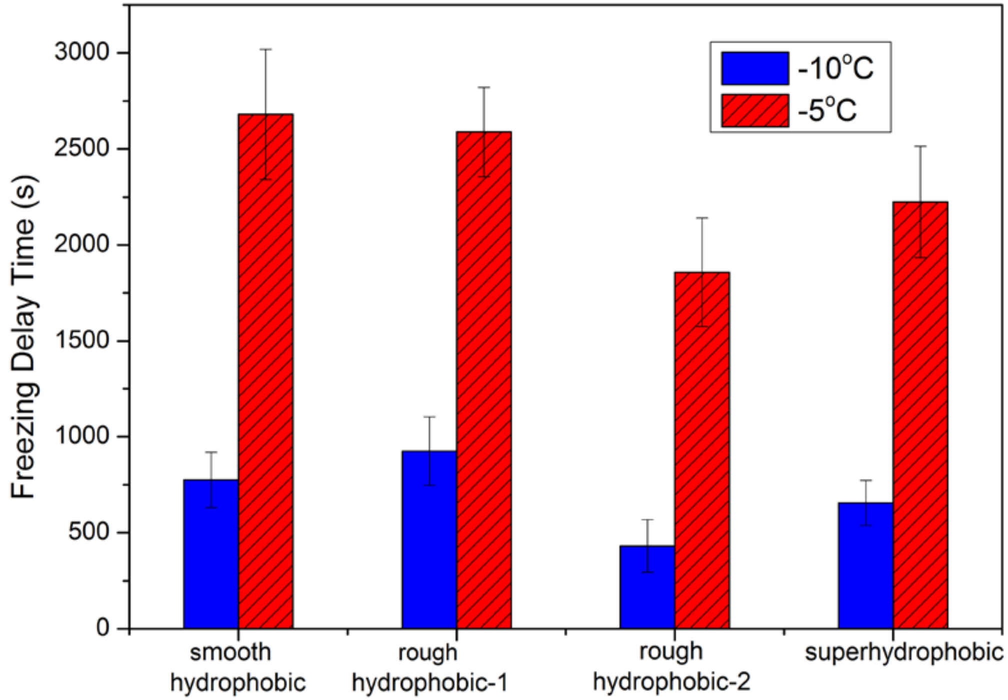
$x = r/r^*$

r* for the temperature range of this work: 5-10 nm

supercooled water freezing delay

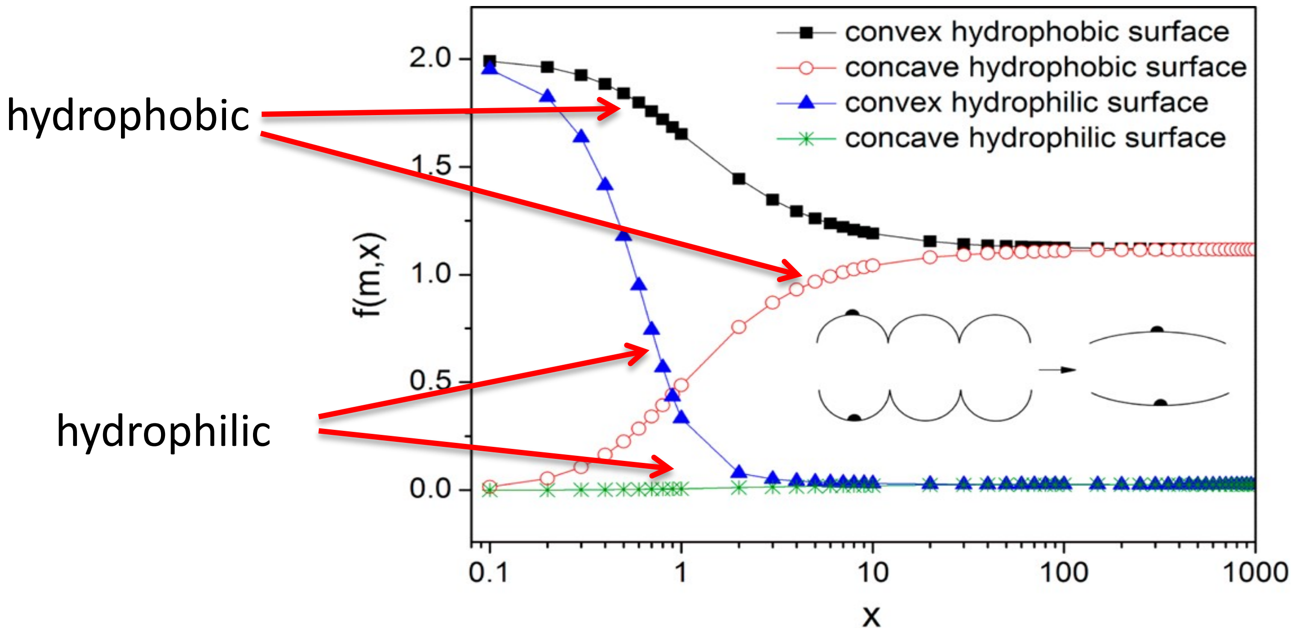
surface	CA (deg)	CA hysteresis (deg)	AFM RMS roughness (nm)
smooth hydrophobic	100±2	13±4	1
rough hydrophobic-1	133±2	54±6	9
rough hydrophobic-2	126±4	38±4	250
superhydrophobic	161±2	0±4	160





supercooled water freezing delay discussion

based on classical theory of heterogeneous nucleation



1. *f*(*m*,*x*) decreases with decreasing contact angle of the ice nucleus

hydrophobic surfaces are preferred over hydrophilic surfaces

2. the larger the radius of the convex surface features, the more readily ice nucleates

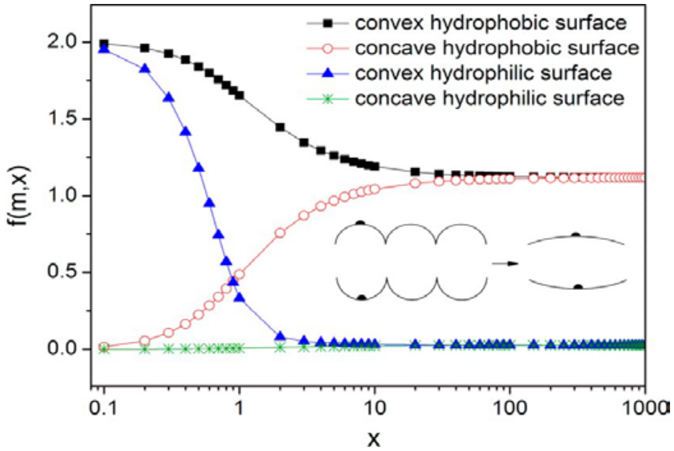
ice nucleates more readily on flat areas than on highly convex areas

3. the dependence of *f*(*x*,*m*) on *x* for convex surface features is rather small for high contact angles

a weak dependence on surface topography for hydrophobic surfaces

Heydari et al., J. Phys. Chem. C 2013, 117, 21752–21762

supercooled water freezing delay discussion



4. real rough surfaces have both convex and concave surface features, and

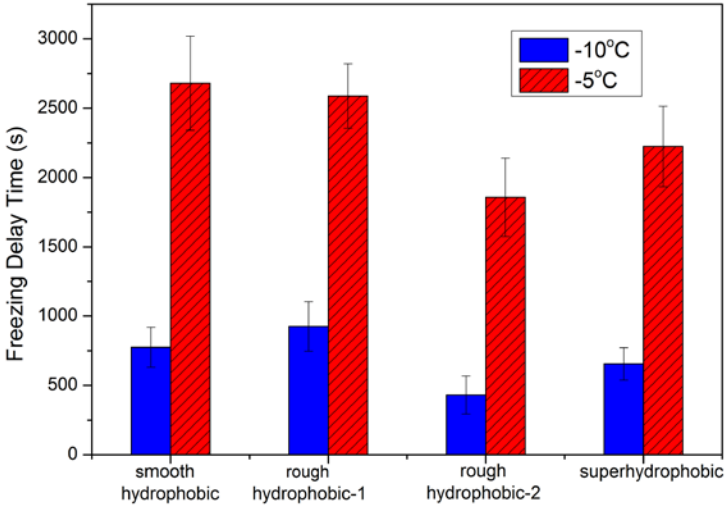
ice nucleates more readily in the concave features

5. *if supercooled water penetrates into the concave sites,* promoted by frost formation or vapor condensation then *ice nucleation occurs most readily on these sites*

- any real surface has a distribution of curvatures
  it is thus too simplistic to choose any single roughness parameter, such as RMS

- Ice nucleation probability depends on the nanoscale surface energy and surface curvature

supercooled water freezing delay discussion



For hydrophobic surfaces

- freezing delay time is not significantly affected by the surface topography or the wetting state

- the small concave sites are penetrated by supercooled water only to a limited extent

- The advantage of a superhydrophobic surface for an anti-icing application may be limited to a kinetic situation

Supercooled Water Wetting & Freezing
on
Hydrophobic and Superhydrophobic Surfaces

Focus on:

2. Surface topography & architecture

surface material:

silica+silicone plasma polymer

wood+LFS deposited titania+ silicone plasma polymer

wood+ silicone plasma polymer

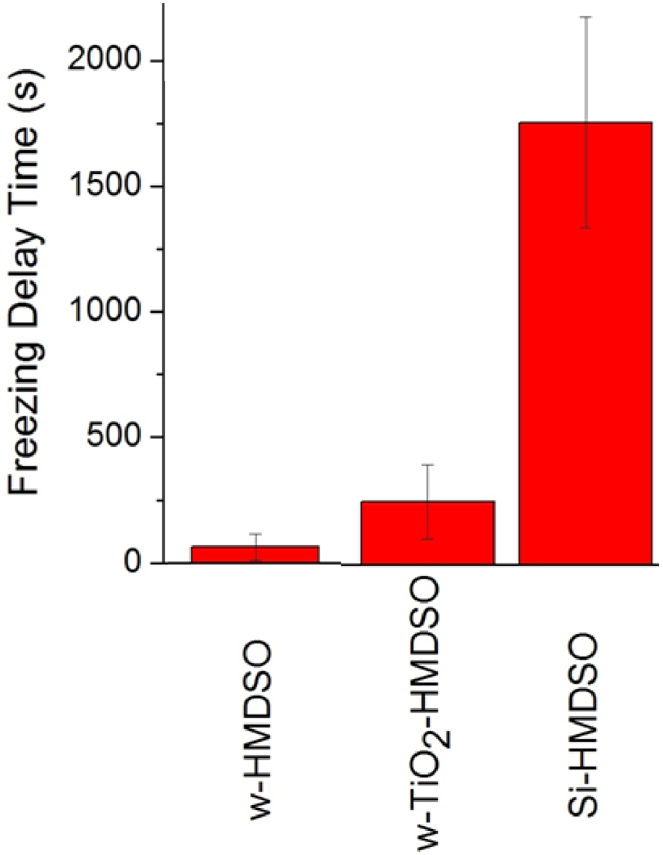
surface topography:

smooth, stochastically rough, multi-scale roughness

wetting state:

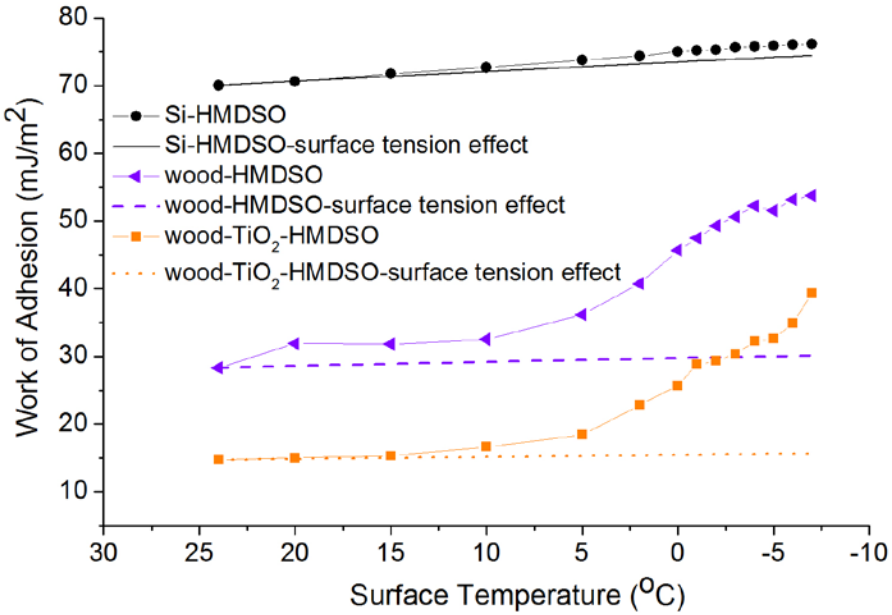
hydrophobic to superhydrophobic (contact angle between 90 to 145)

supercooled water freezing delay at -4°C



- the multi-scale roughness provides some benefit by decreasing the penetration of supercooled water into surface depressions

- flat hydrophobic surface is more promising than superhydrophobic surface



Thanks for your attention!