Démouillage sur surfaces hétérogènes - comment relier approche locale et réponse macroscopique ?

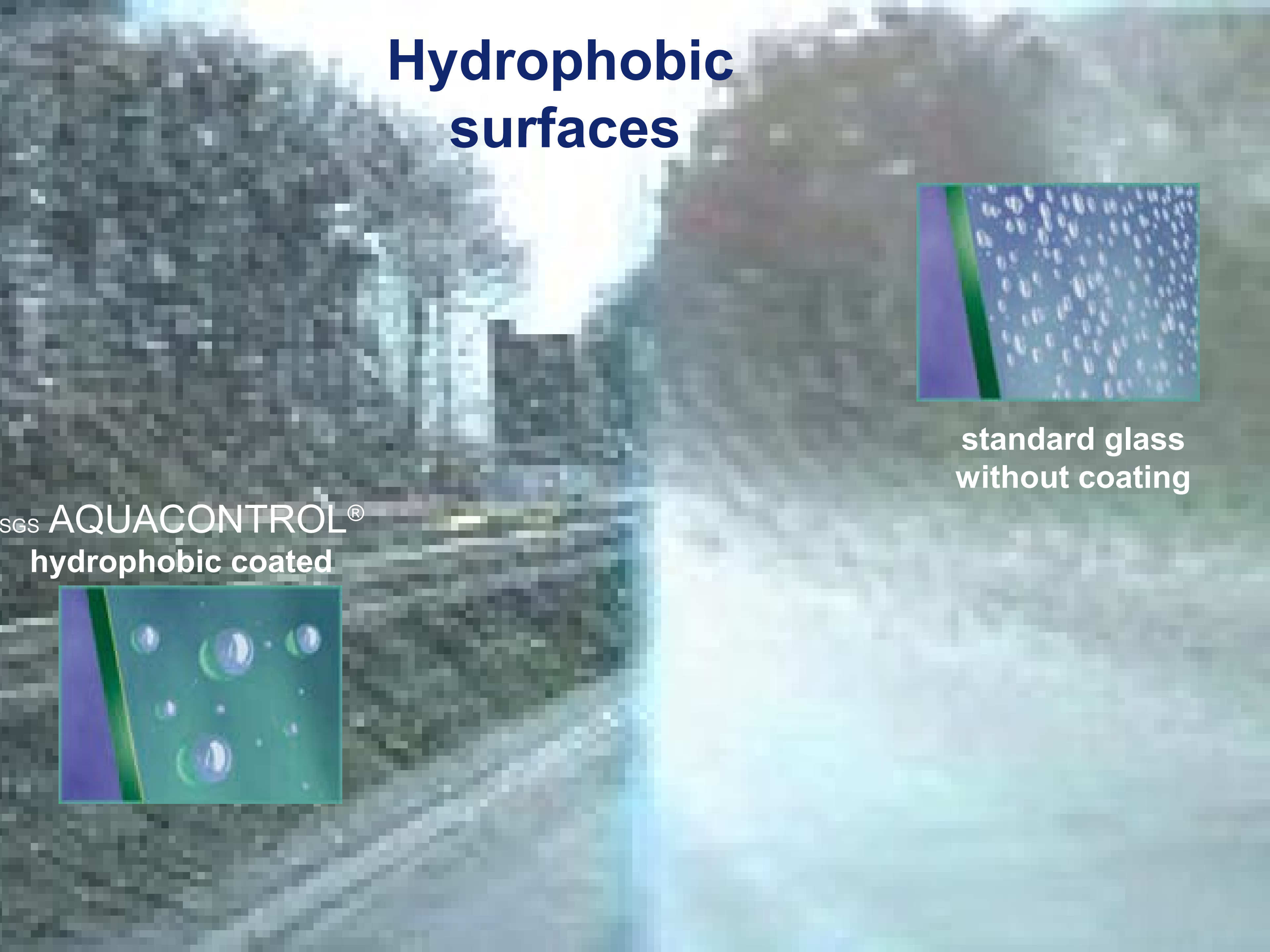
A. Gauthier, E. Contraire, M. Rivetti, P. Hayoun, J. Teisseire

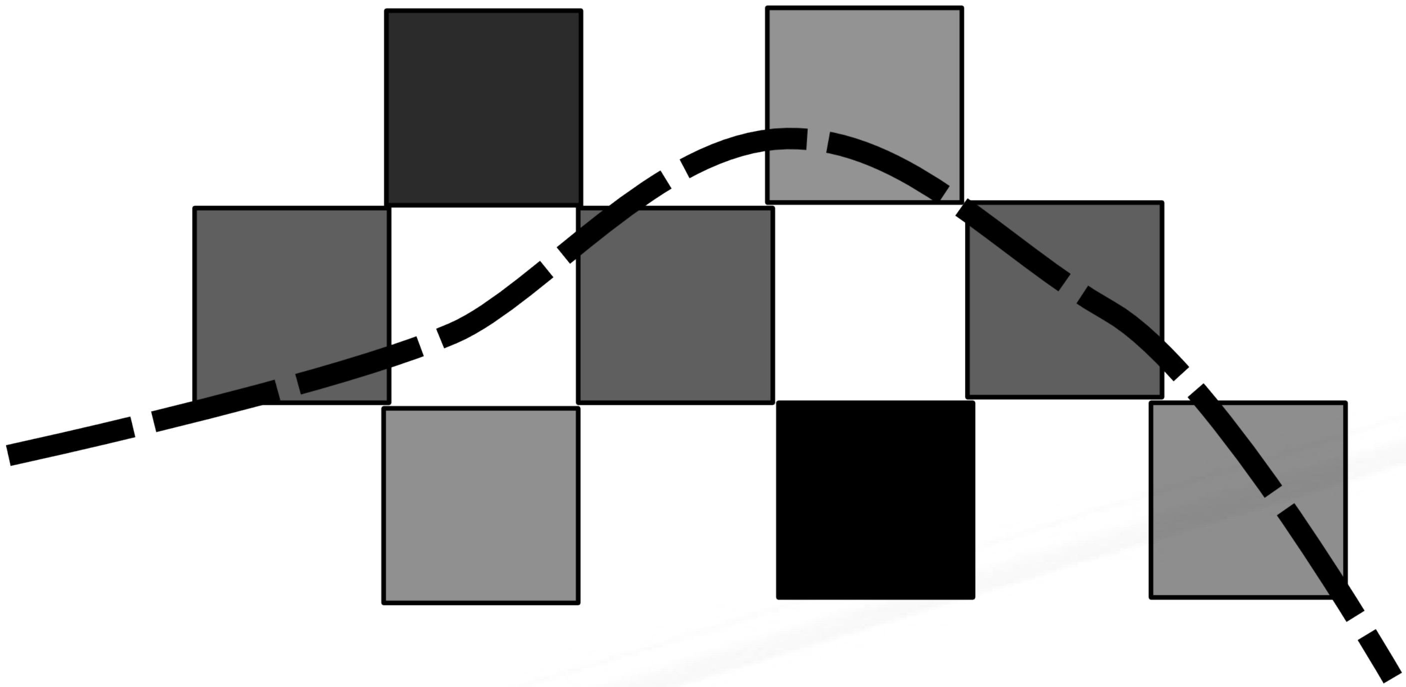
Surface du Verre et Interfaces, CNRS/Saint-Gobain

and E. Verneuil, F. Lequeux and E. Barthel*

SIMM ESPCI

Hydrophobic surfaces





Pomeau JCIS 1985

Young's
Young's
equation

III. *An Essay on the Cohesion of Fluids.* *By* Thomas Young, *M. D. For. Sec. R. S.*

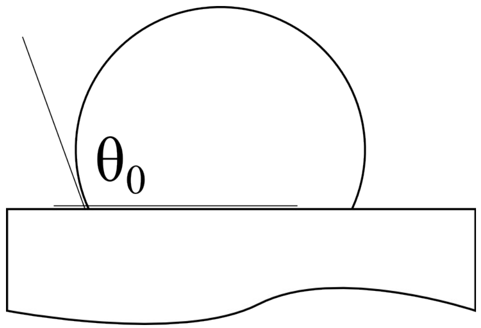
Read December 20, 1804.

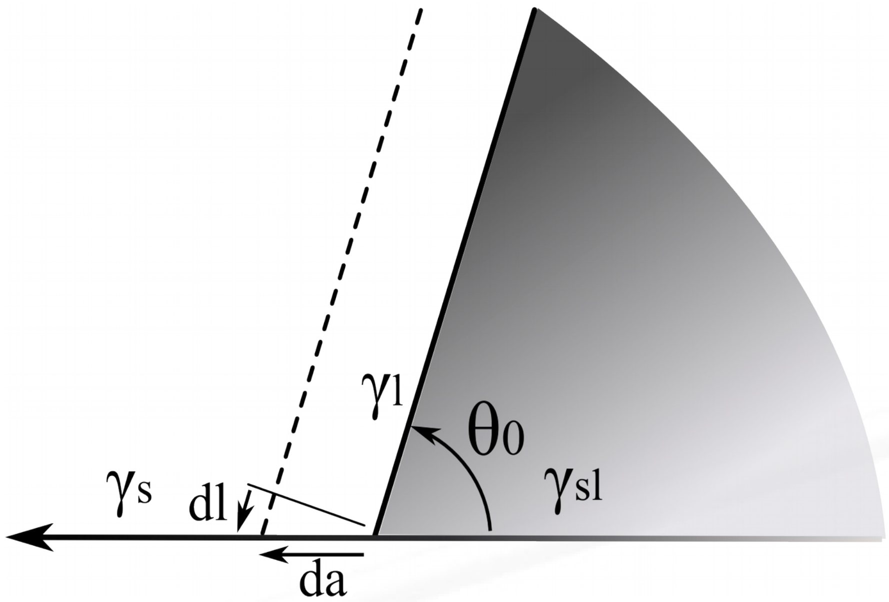
I. *General Principles.*

It has already been asserted, by Mr. Monge and others, that the phenomena of ca[...] attraction of the su[...] ployed, and that the[...] into curves of the nat[...] the results of a uni[...] pressure of a fluid, [...]

Now, supposing the angle of the fluid to be obtuse, the whole superficial cohesion of the fluid being represented by the radius, the part which acts in the direction of the surface of the solid will be proportional to the cosine of the inclination; and this force, added to the force of the solid, will be equal to the force of the common surface of the solid and fluid, or to the differences of their forces; consequently, the cosine added to twice the force of the solid, will be equal to the whole force of the fluid, or to the radius: hence the force of the solid is represented by half the difference between the cosine and the radius, or by half the versed sine; or, if the force of the fluid be represented by the diameter, the whole versed sine will indicate the force of the solid. And the same result follows when the angle of the fluid is acute. Hence we may infer, that if the solid have half

Contact angle – Young's equation





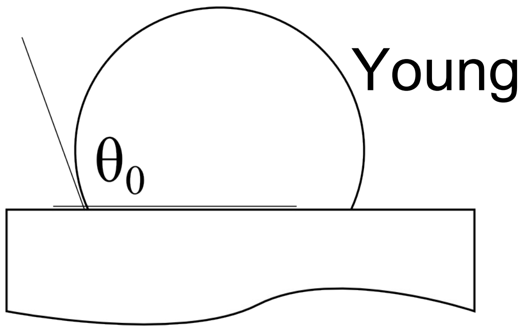
$$\gamma_l \, dl + (\gamma_{sl} - \gamma_s) \, da = 0$$

$$da \cos \theta_0 = dl$$

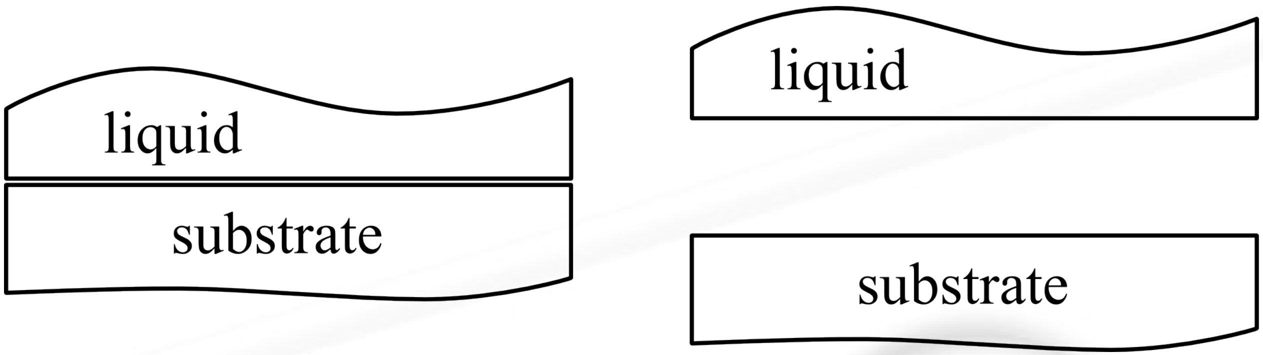
$$\gamma_s - \gamma_{sl} = \gamma_l \cos \theta_0$$

Contact angle and adhesion

Young-Dupré equation



$$\gamma_s - \gamma_{sl} = \gamma_l \cos\theta_0$$



$$w_{eff} = \gamma_s + \gamma_l - \gamma_{sl} = \gamma_l (1 + \cos\theta_0)$$

CONTACT ANGLES

By A. B. D. Cassie

Received 27th January, 1948

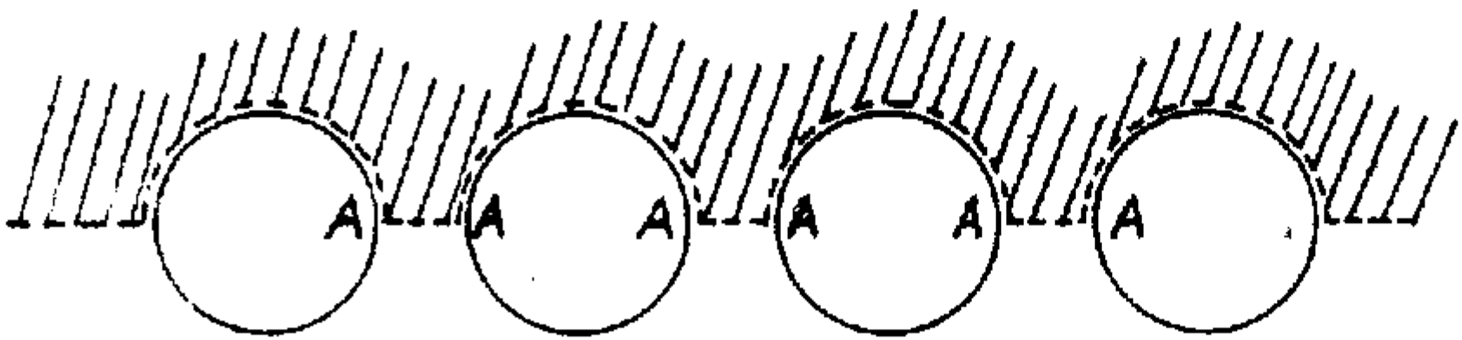
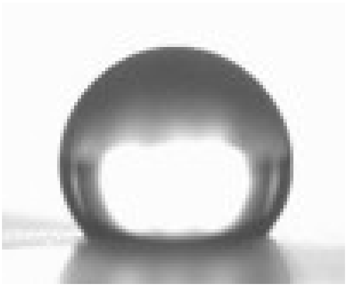


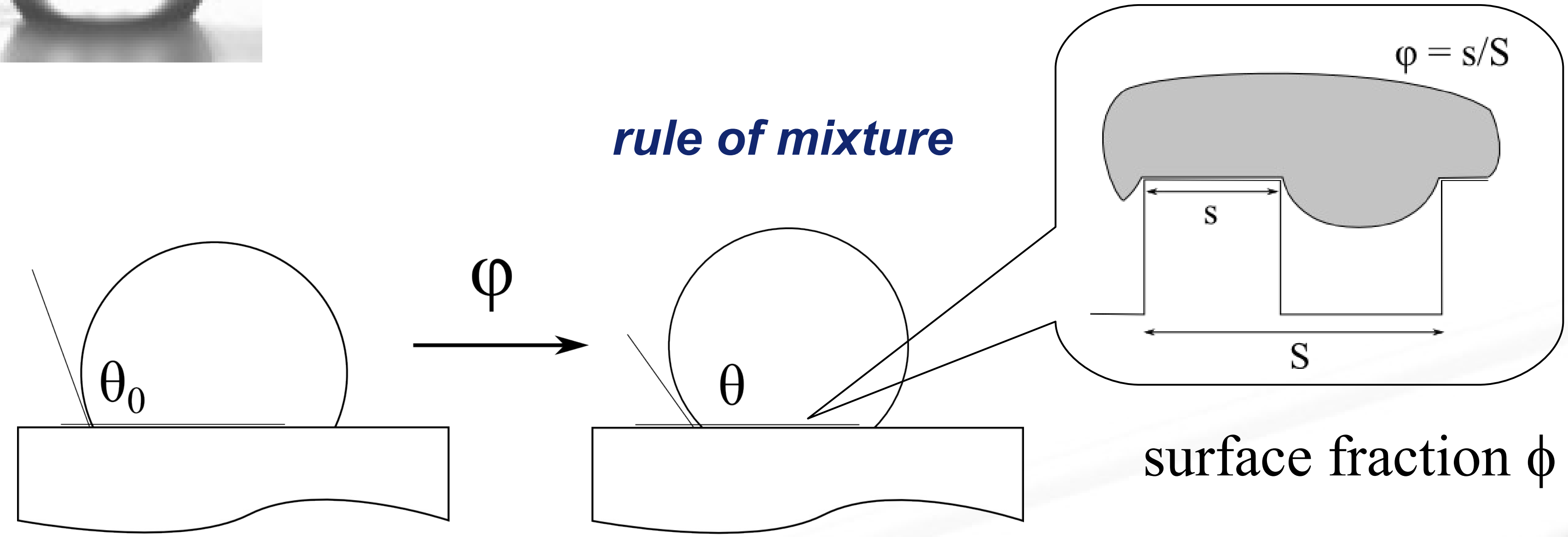
Fig. 1.—Water on cylinders.

Cassie and Baxter, Trans. Farad. Soc. 1944



Superhydrophobic surfaces
Cassie model

rule of mixture

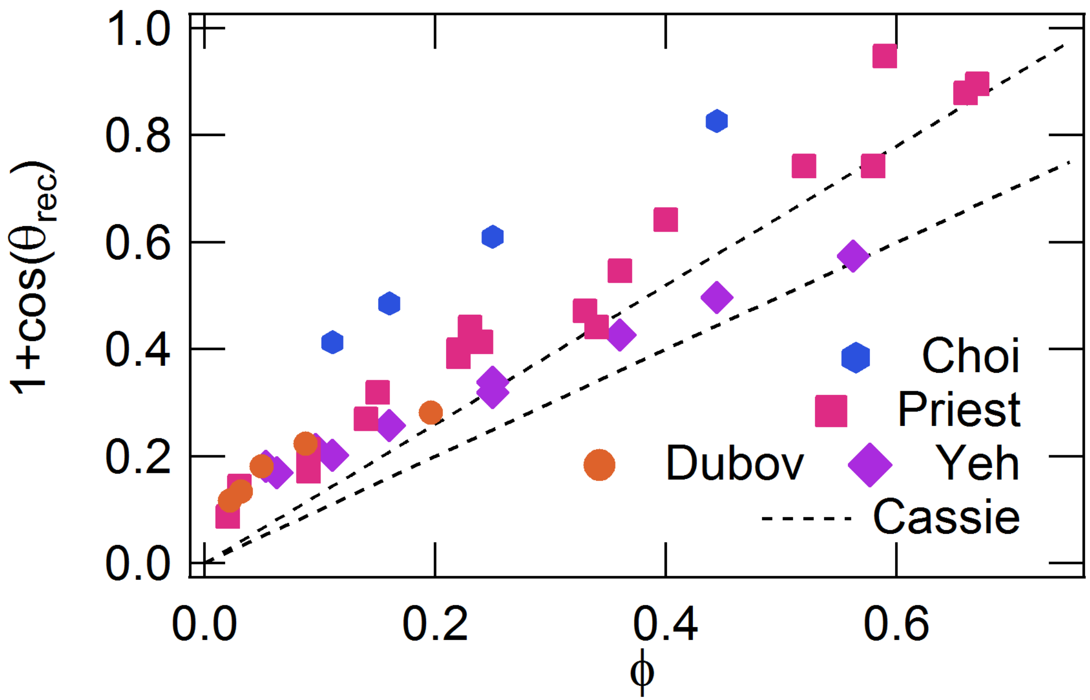


surface fraction ϕ

$$\frac{w}{\gamma_l} = 1 + \cos\theta = \phi(1 + \cos\theta_0)$$

Cassie and Baxter, Trans. Farad. Soc. 1944
Bico et al. EPL 1998

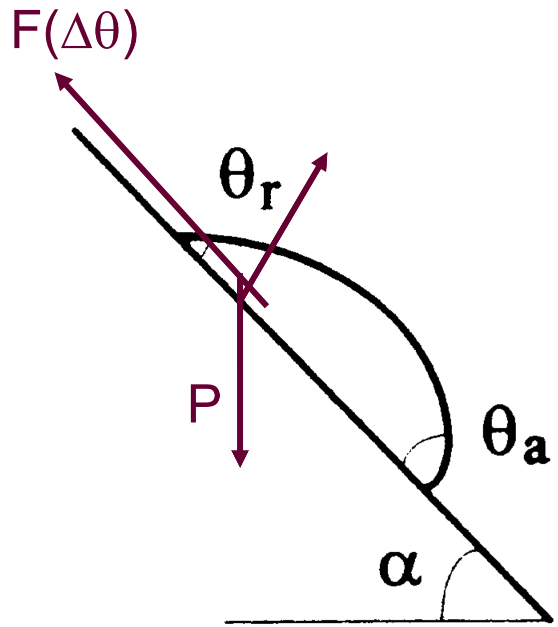
Does scale with surface fraction **but not** really proportional

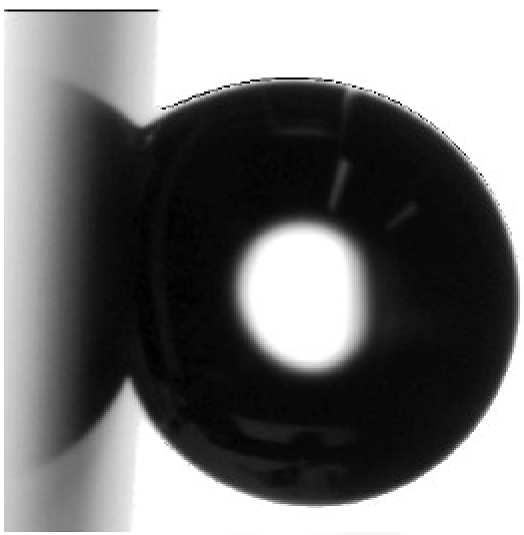


Yeh et al Langmuir 2008
Priest et al Langmuir 2009
Choi et al JCIS 2009
Dubov et al EPL 2011

see Erbil Surf Sci Rep 2014 for a review

Contact angle hysteresis





Dorrer and Rühe,
Beilstein J. Nanotechnol. 2011

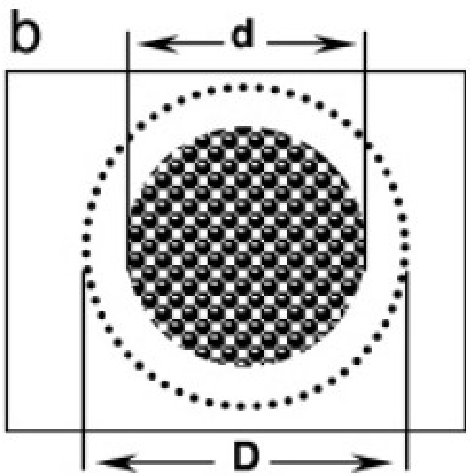
$$\pi r\gamma(\cos\theta_r - \cos\theta_a) < \rho g V \sin\alpha$$

Quéré et al. Langmuir 1998

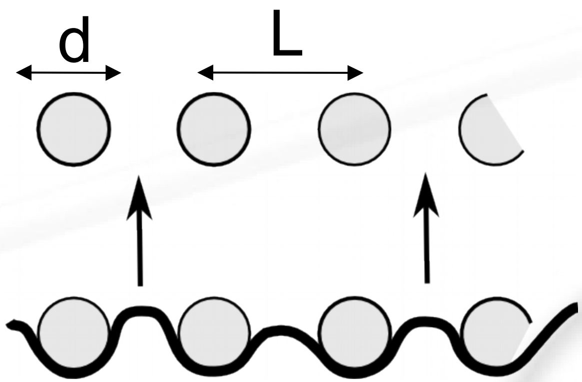
Langmuir **2007,** *23,* 3762−3765

How Wenzel and Cassie Were Wrong

Lichao Gao and Thomas J. McCarthy*



Gao and McCarthy Langmuir 2007
Extrand Langmuir 2004

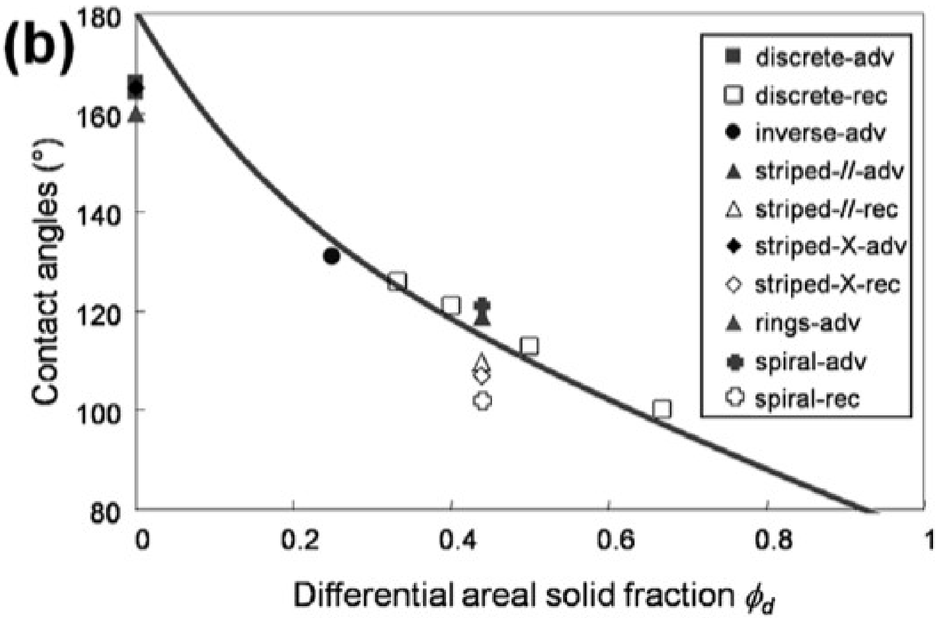


line fraction $\phi_d = d/L$

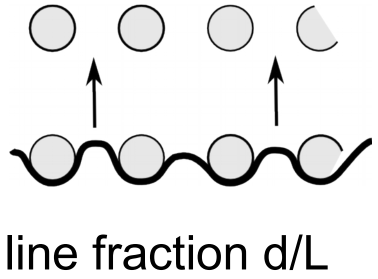
Choi et al. JCIS 2009

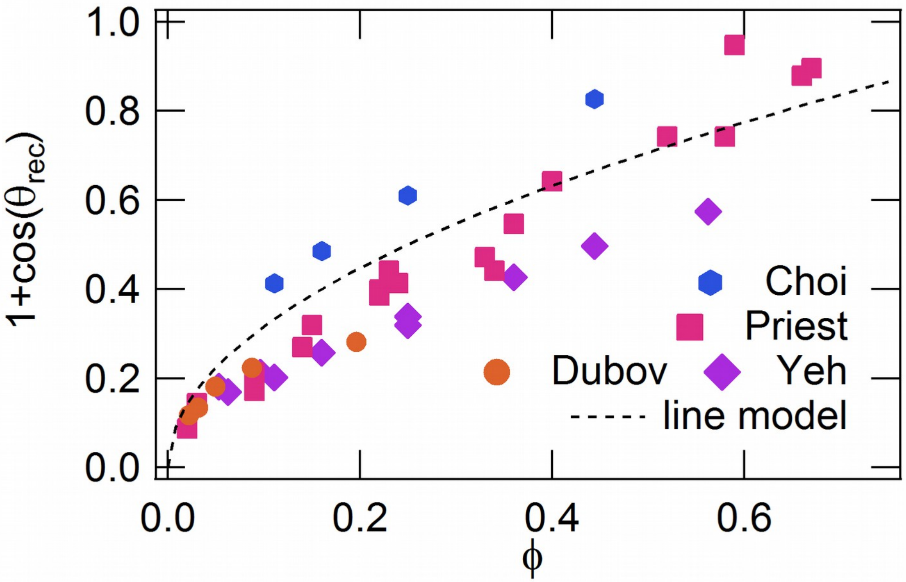
Look at the line...

Line model – Results

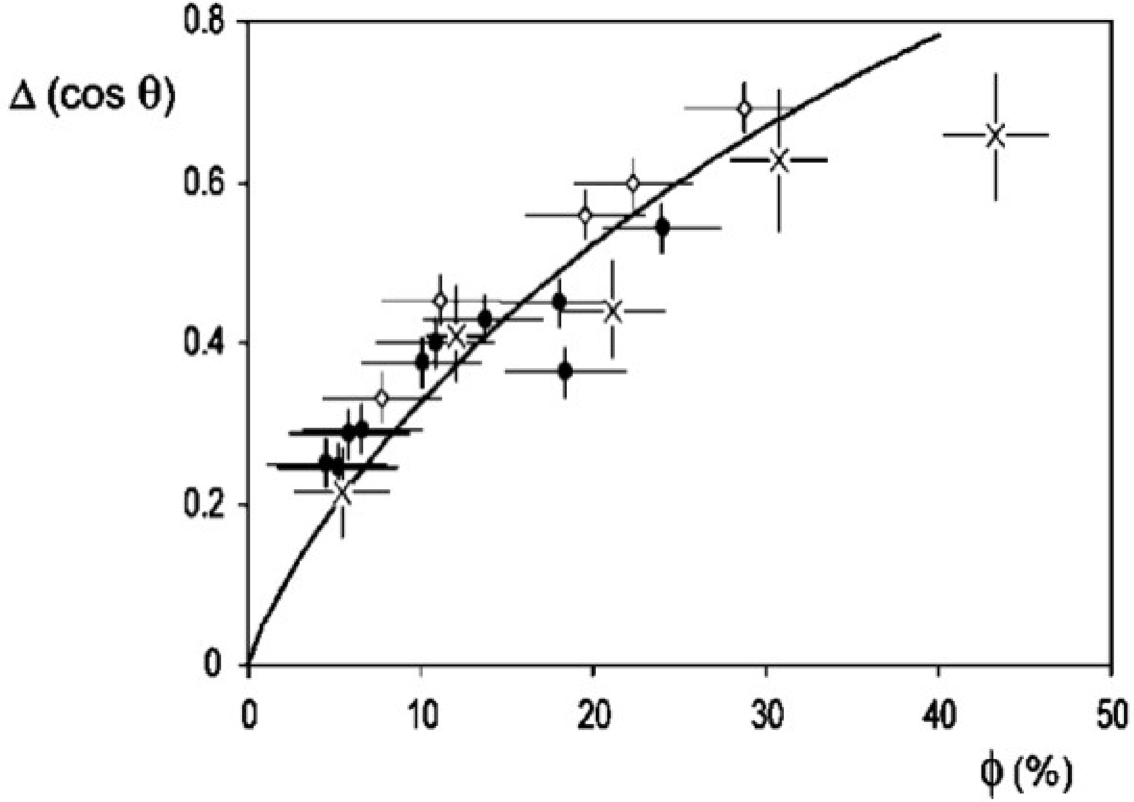


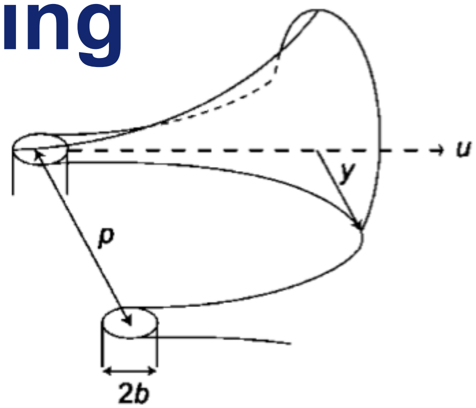
Choi et al. JCIS (2009)





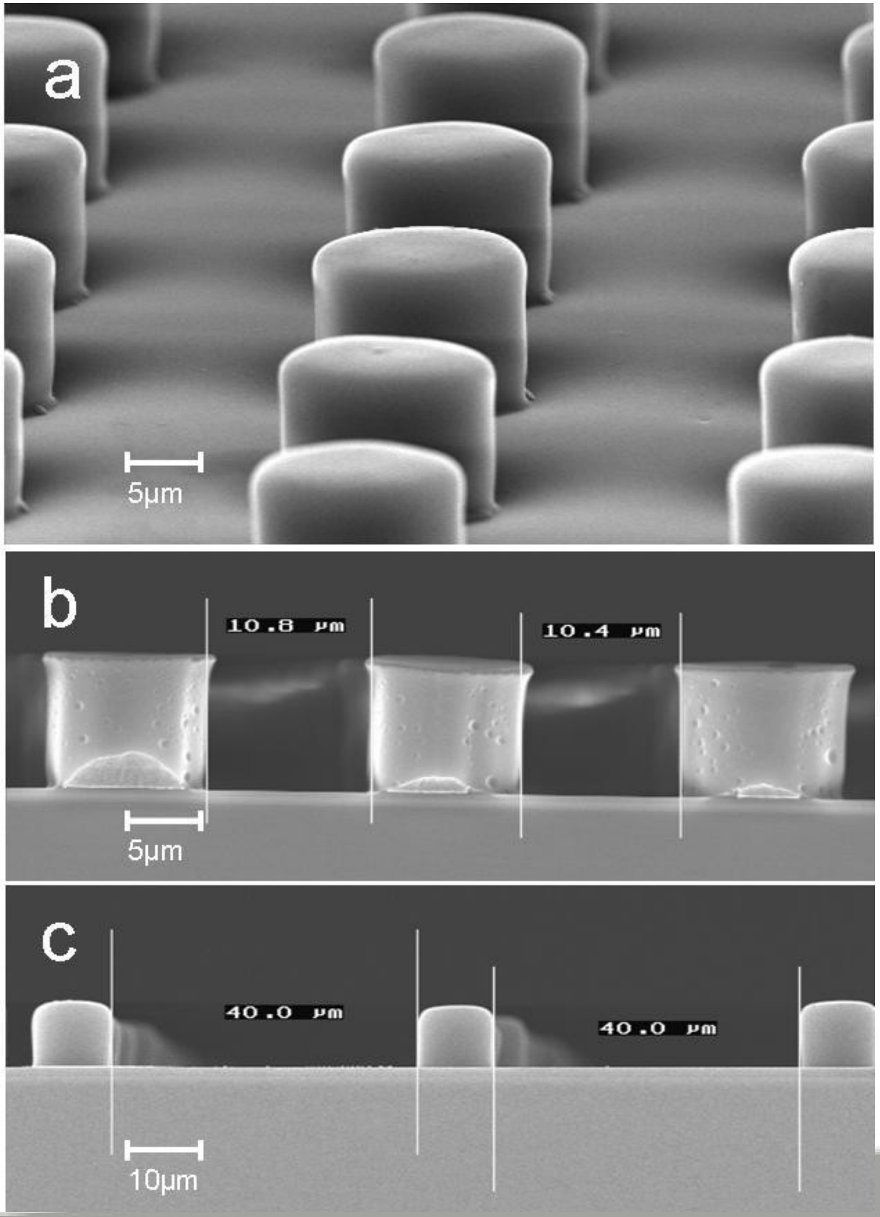
Contact angle hysteresis – Pinning

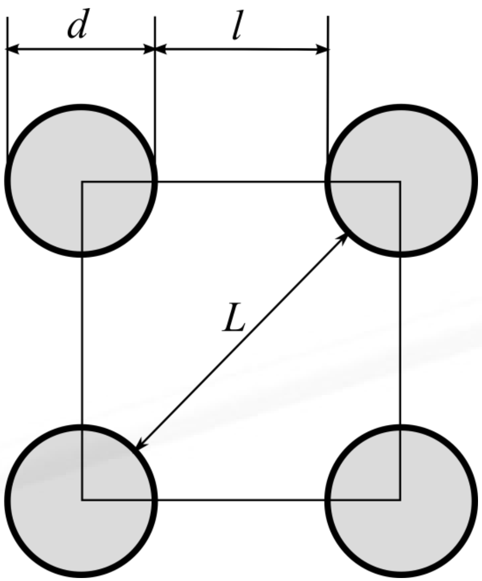




Joanny and de Gennes J. Phys Chem (1984)
Paterson and Fermigier Phys. Fluids 9 (1997) 2210
Reyssat and Quéré J. Phys Chem B (2009)

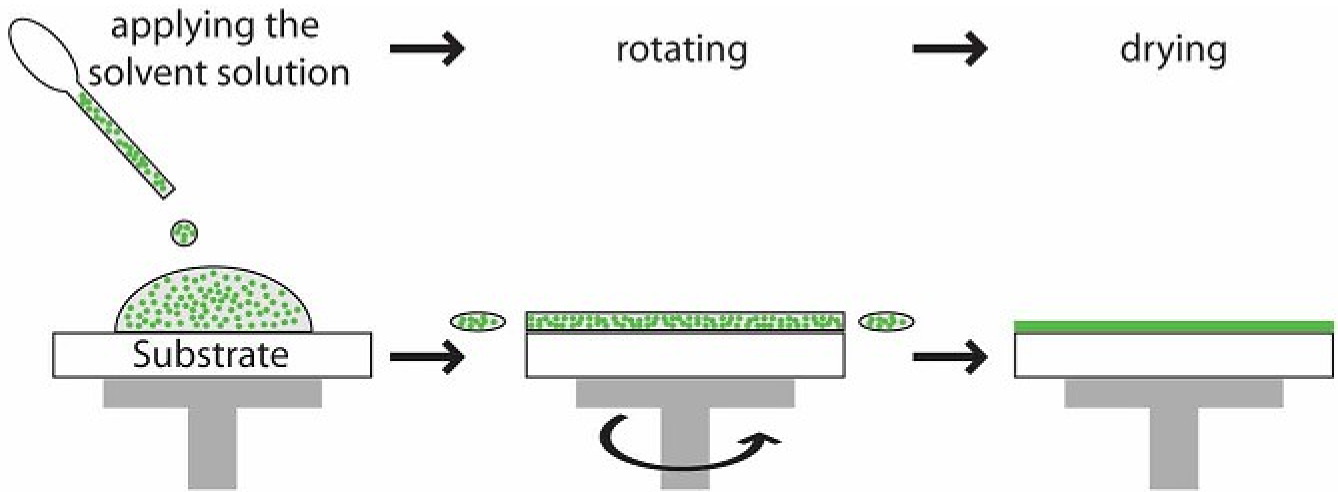
Imprinted surfaces



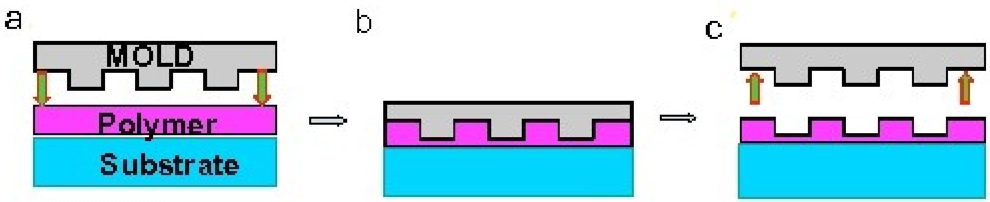


Film deposition

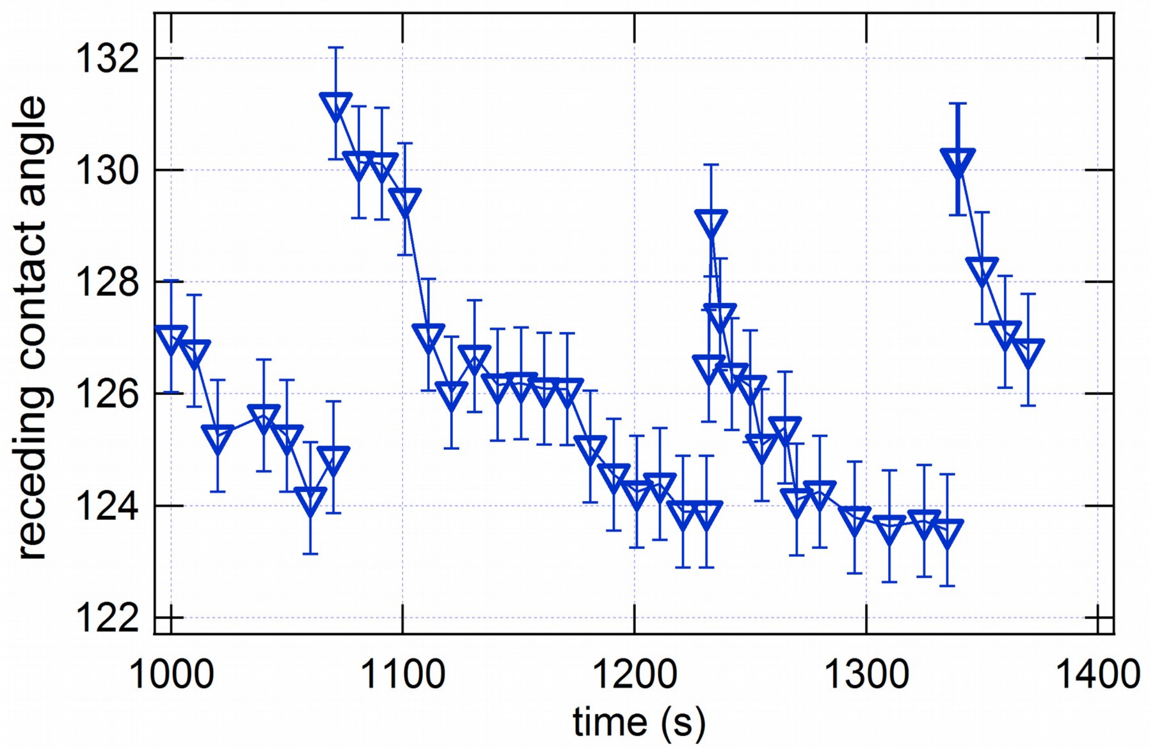
- spin coating



- Embossing



Receding contact angle
square lattice

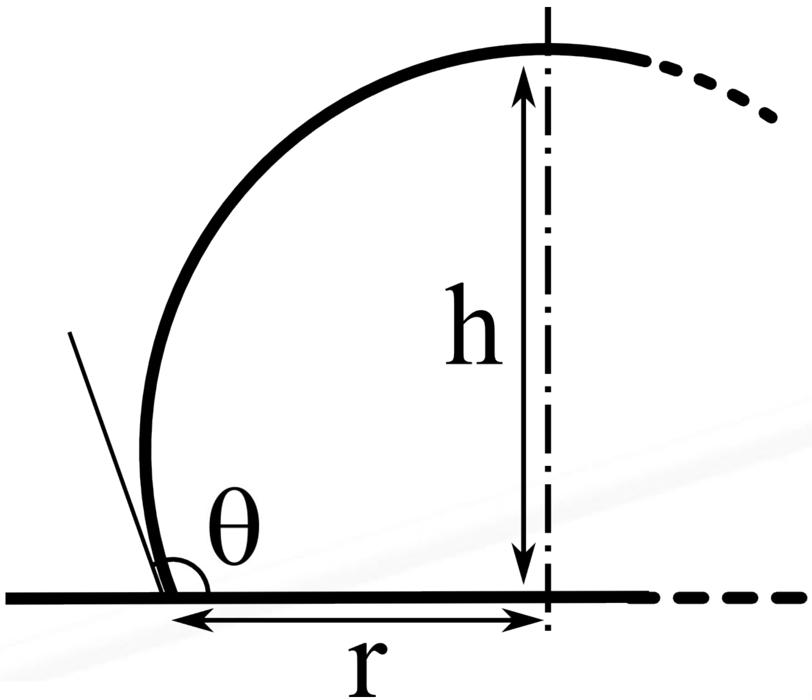


McHale et al. Langmuir (2005)

Gauthier et al. Langmuir 2014

Receding contact angle

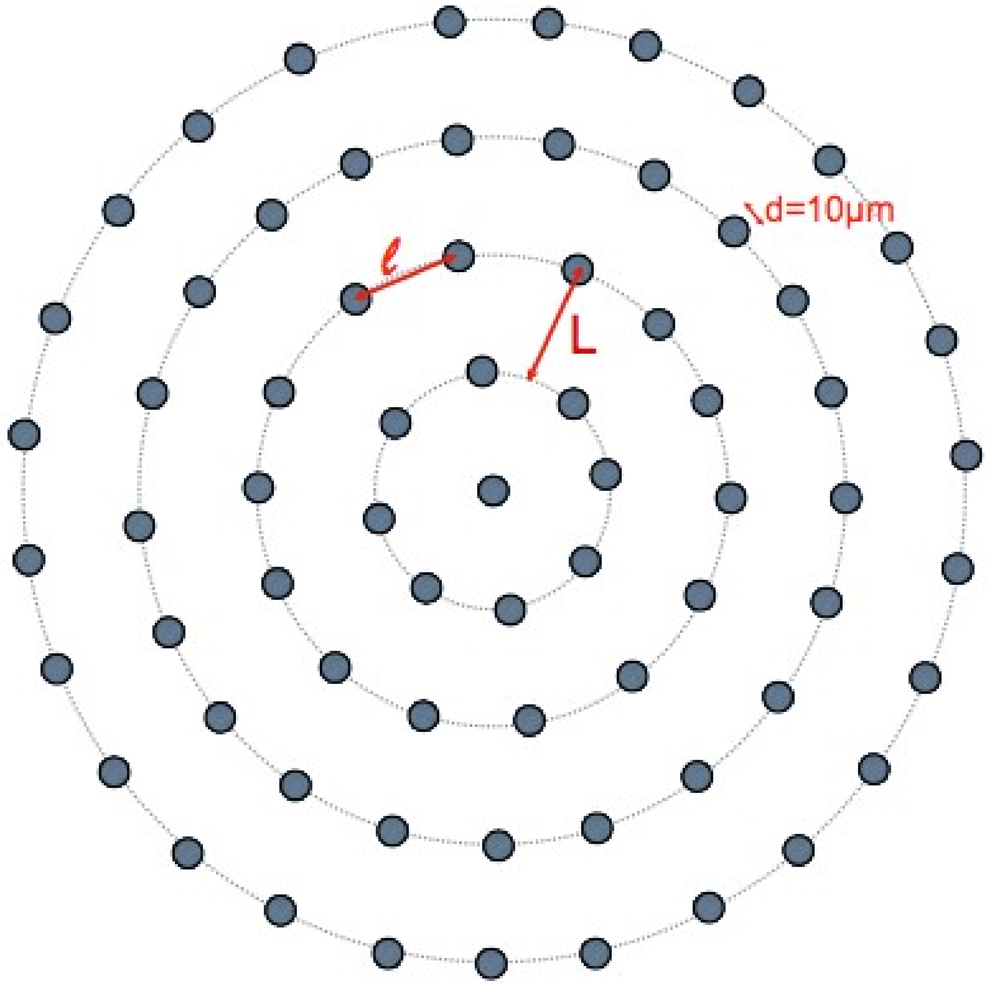
axisymmetric model



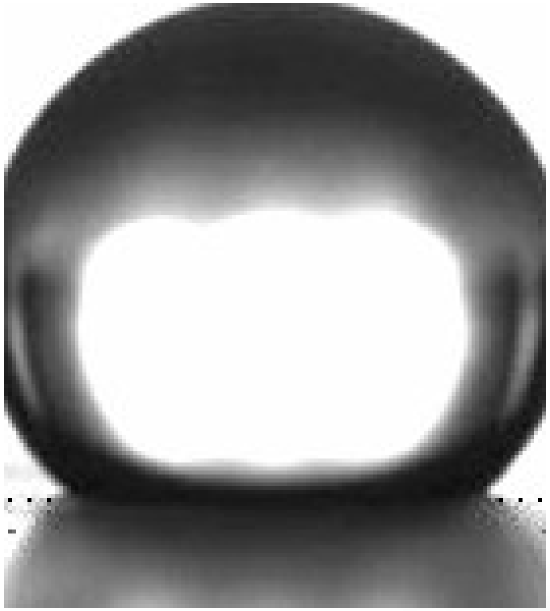
$$\delta\theta = \sin\theta(2+\cos\theta)\frac{\delta r}{r}$$

Shanahan Langmuir 1995
McHale et al. Langmuir 2005

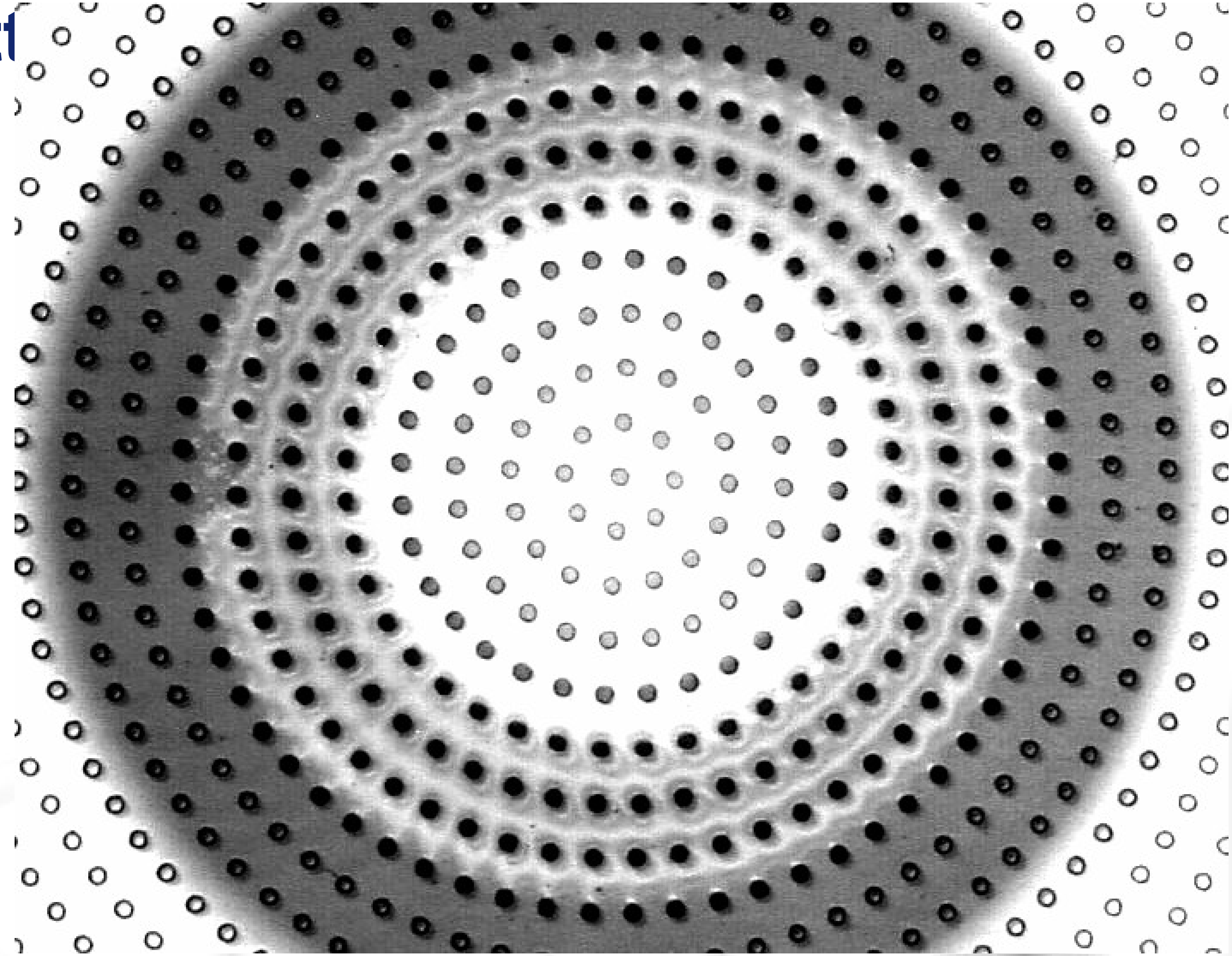
An axisymetric texture



Evaporation on axisymmetric surface – side view

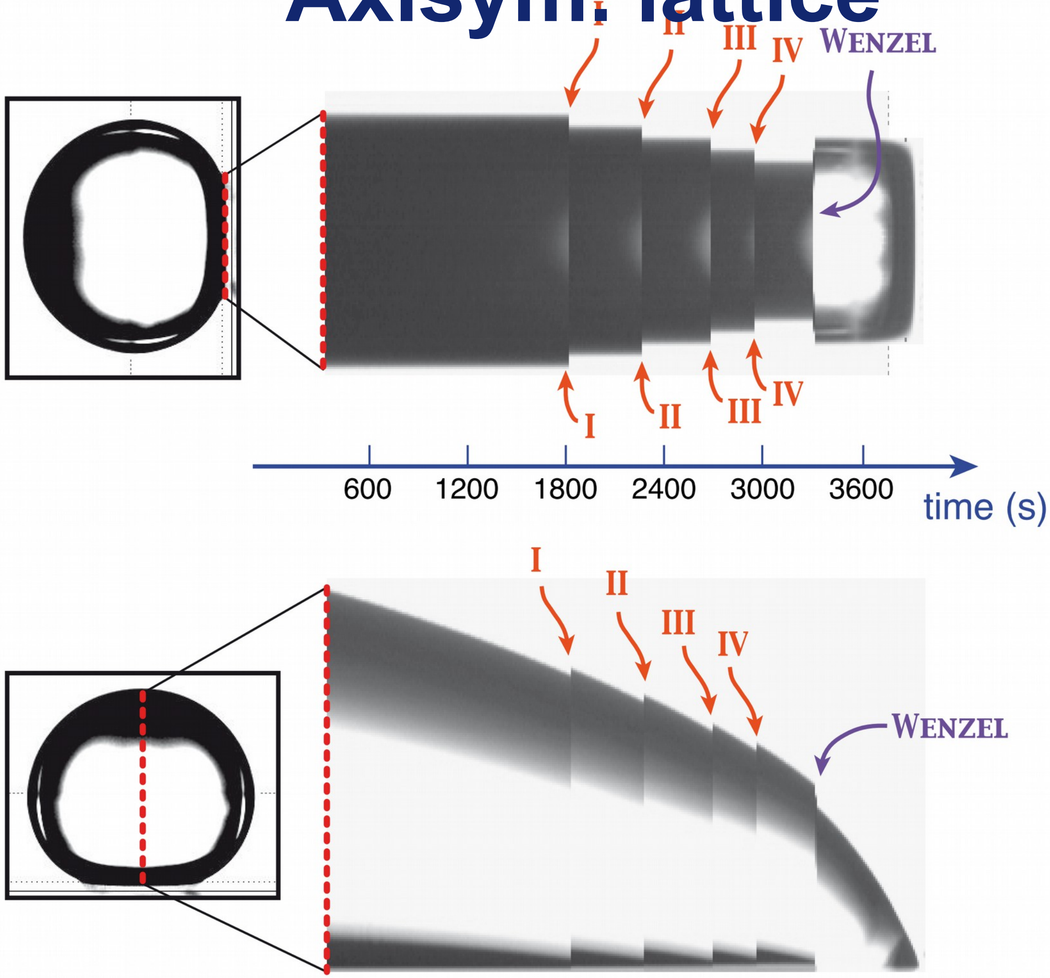


Evaporation on axisymmetric surface – bott

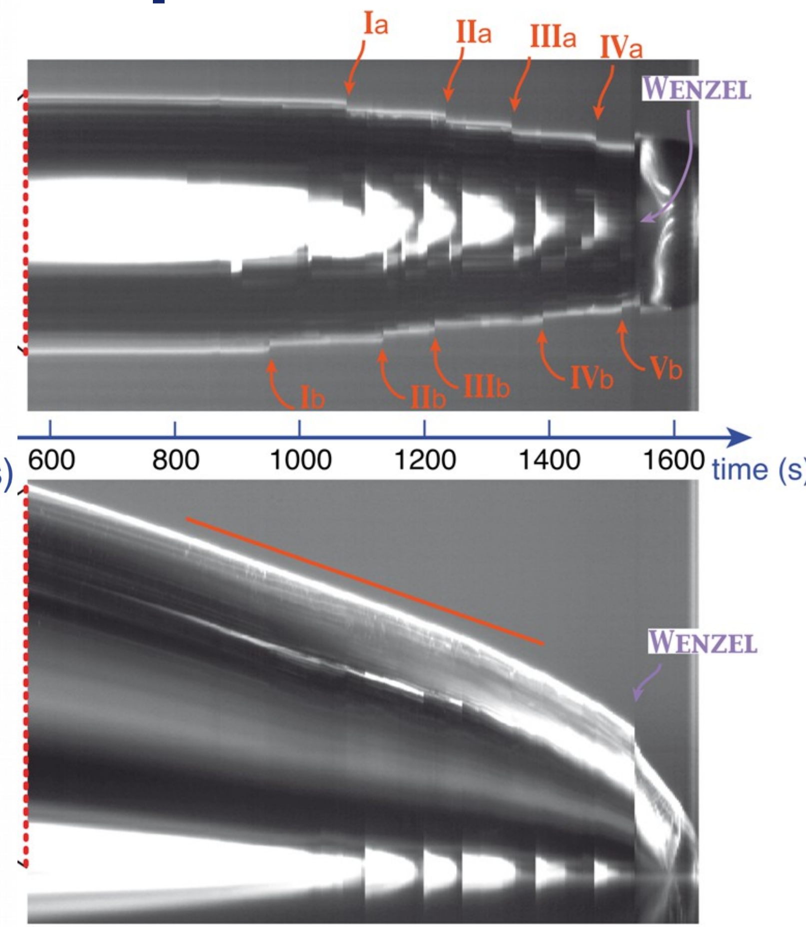


Drop shape

Axisym. lattice

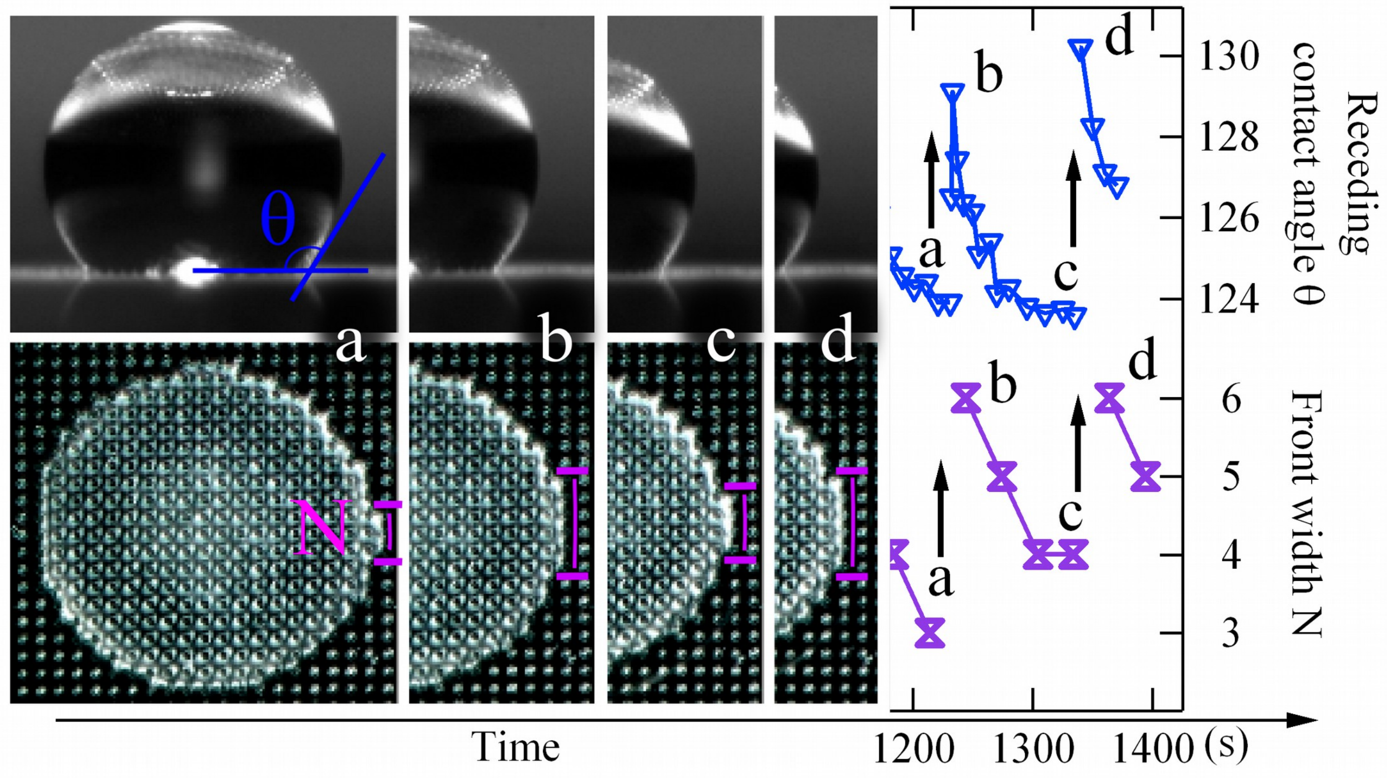


Square lattice



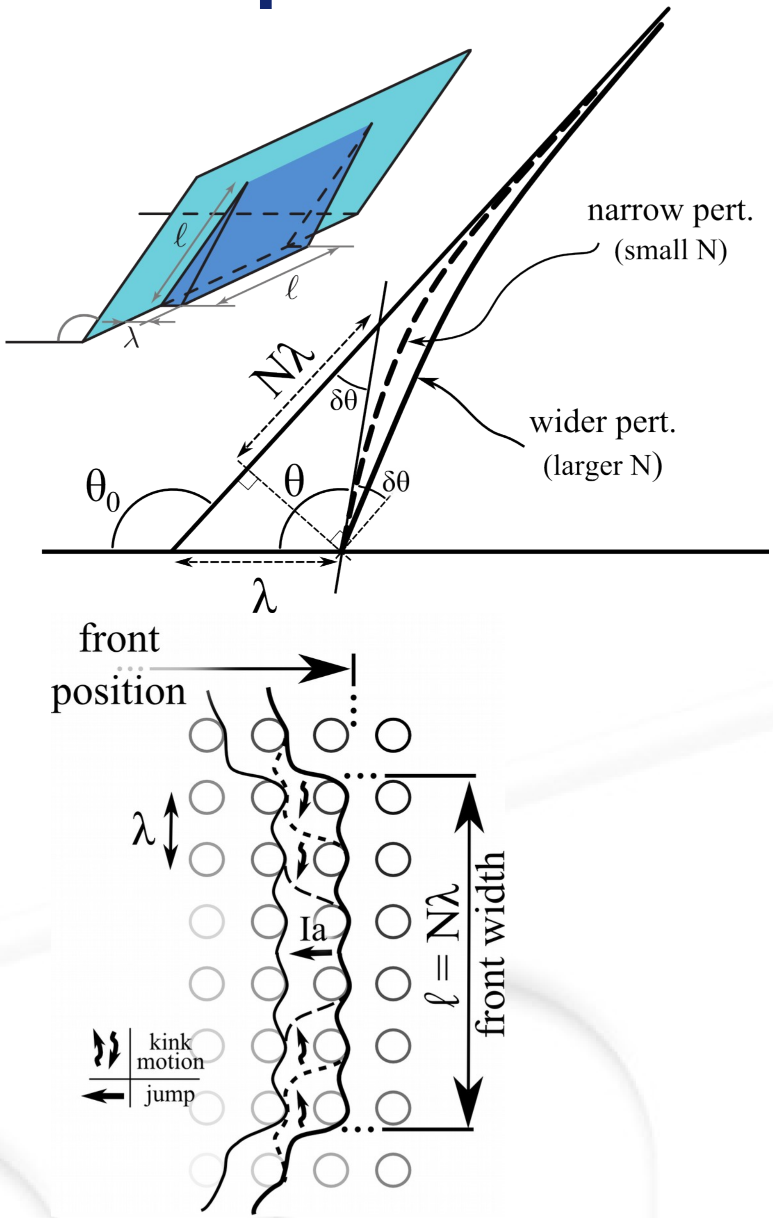
Gauthier et al. Langmuir 2014

Drop shape – square lattice



Gauthier et al. Langmuir 2014

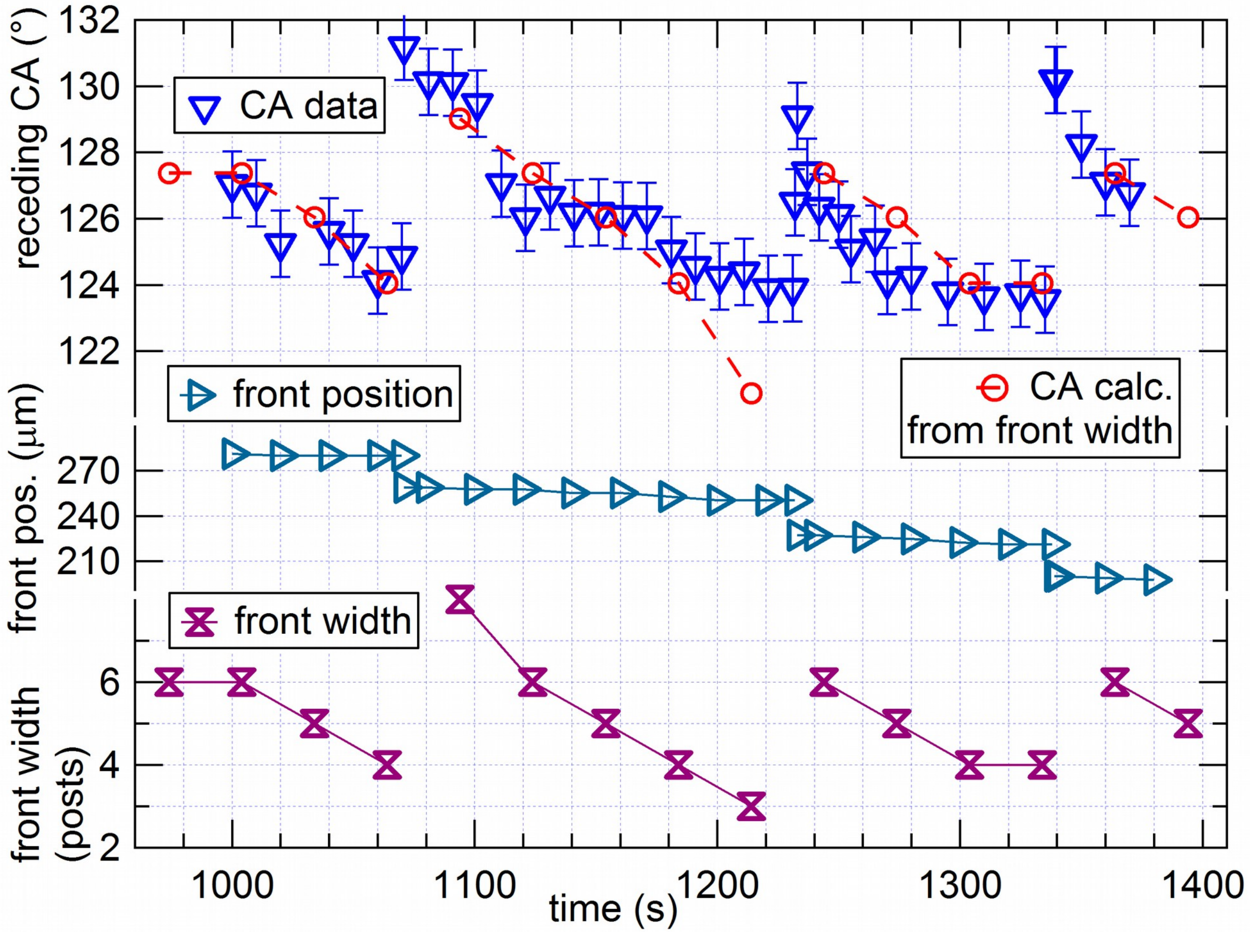
Macroscopic contact angle – square lattice



$$\theta = \theta_0 - \frac{\sin \theta_0}{N}$$

Gauthier et al. Langmuir 2014

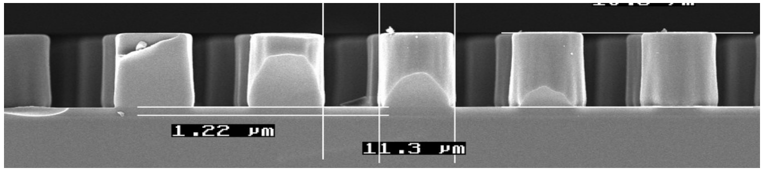
Macroscopic contact angle – square lattice

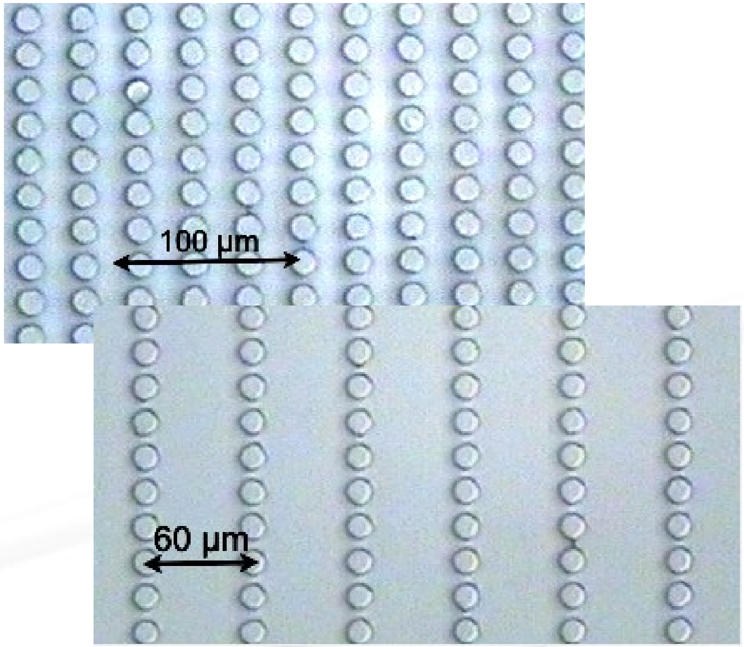


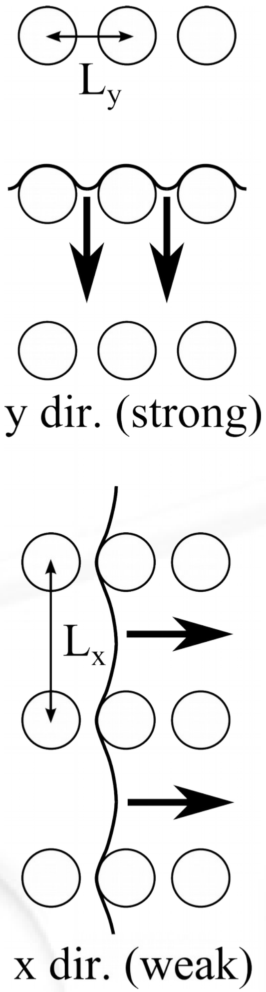
$$\theta = \theta_0 - \frac{\sin \theta_0}{N}$$

Gauthier et al. Langmuir 2014

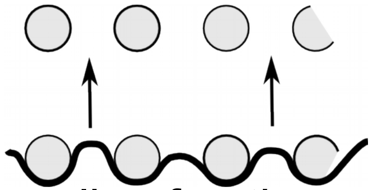
Rectangular arrays

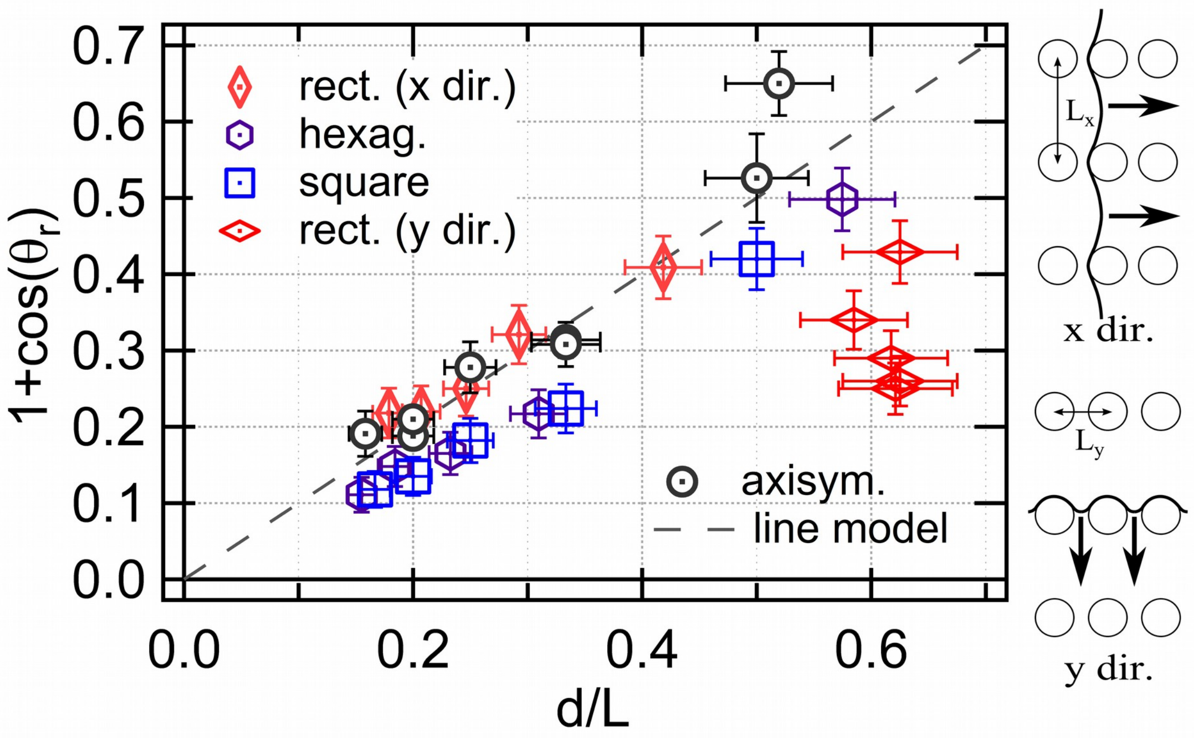


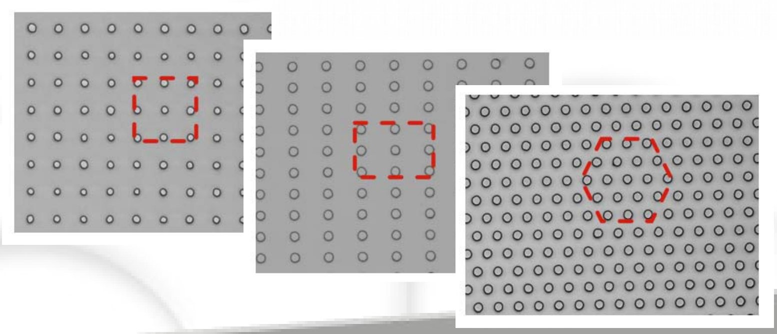




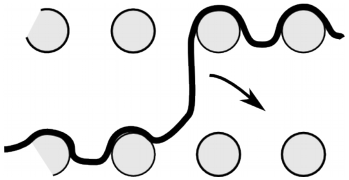
Receding contact angle
Impact of lattice

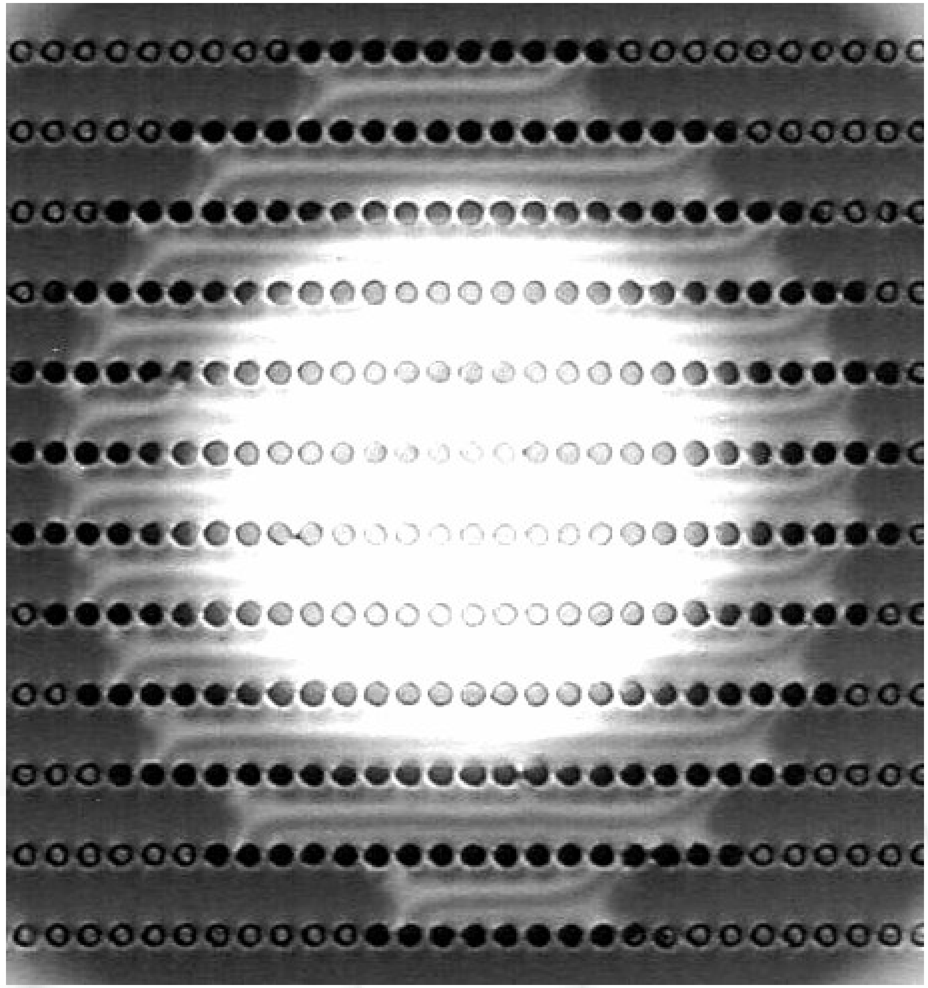




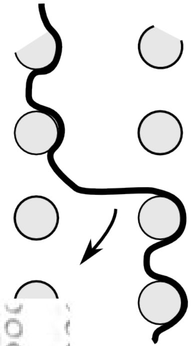


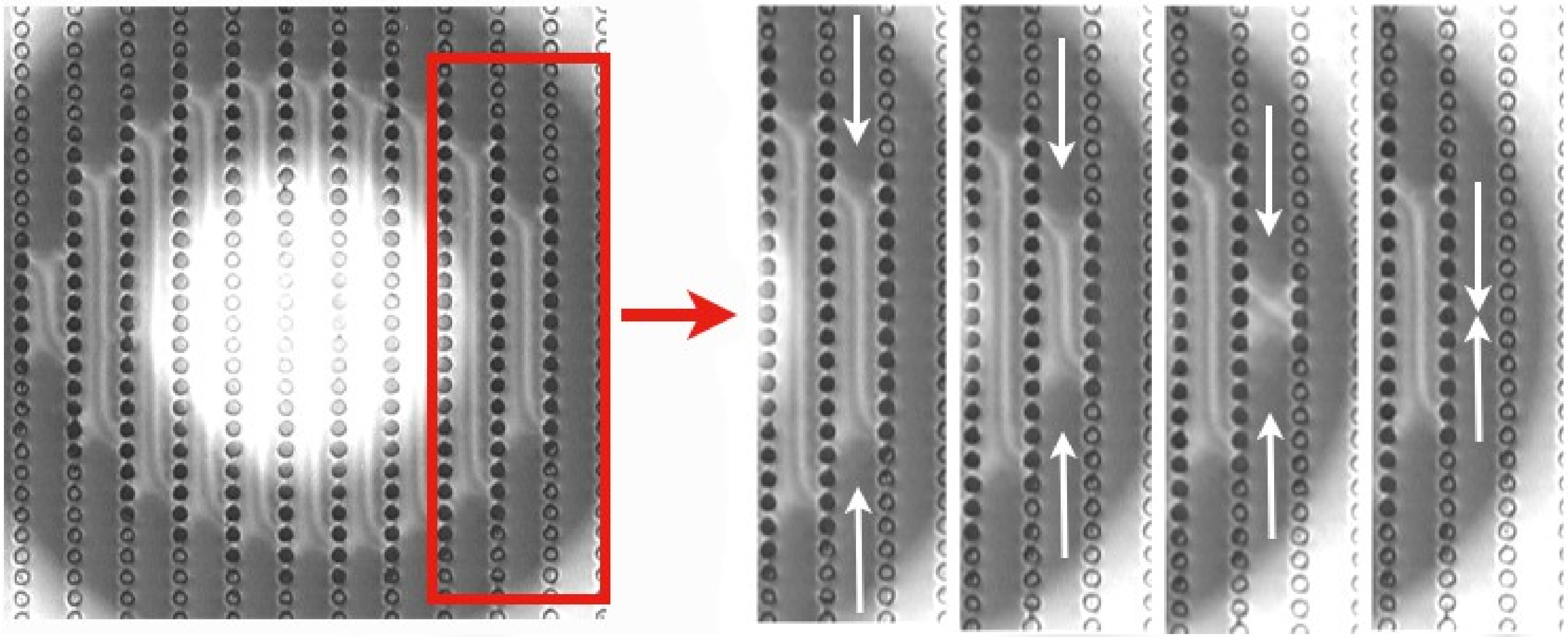
Rivetti et al. PRL 2015



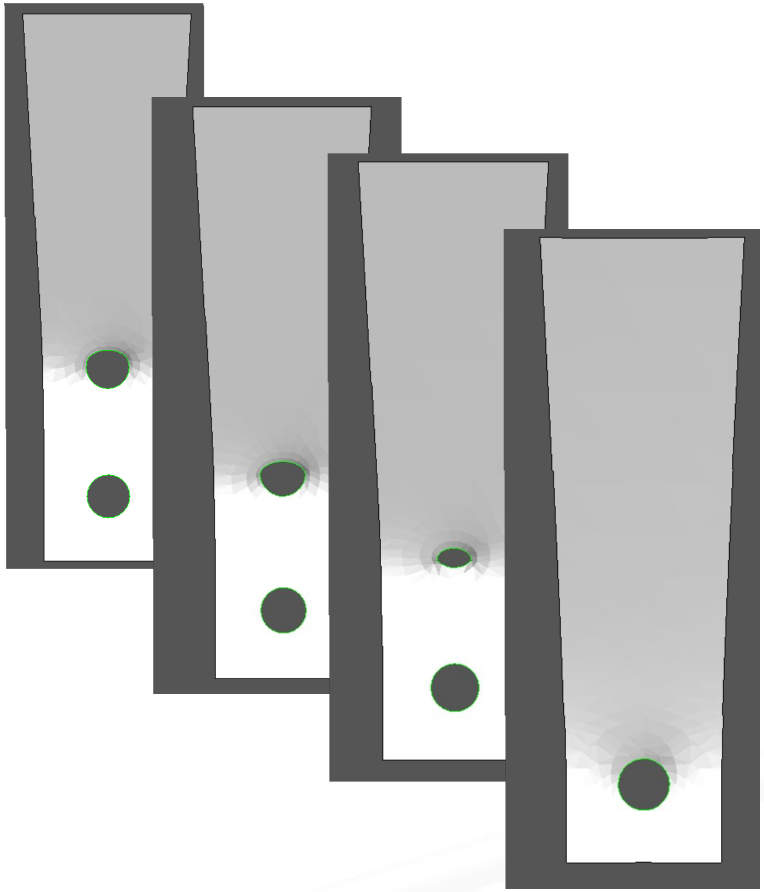


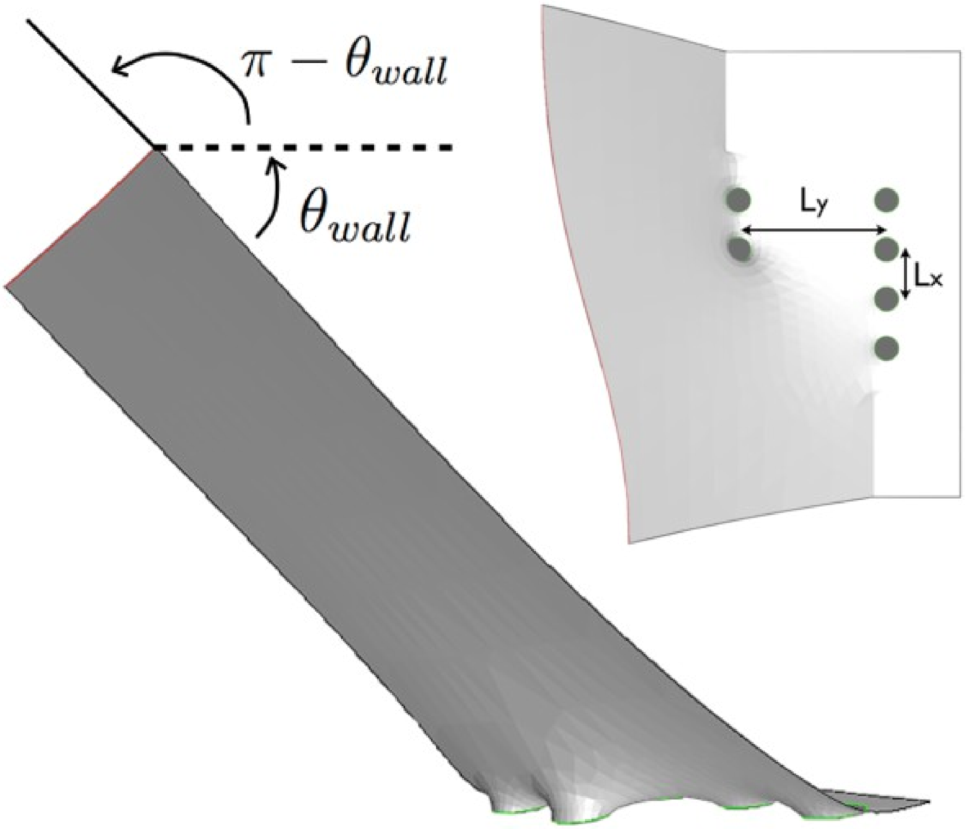
Front Propagation Mechanism





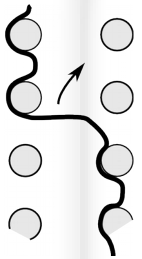
Numerical simulations

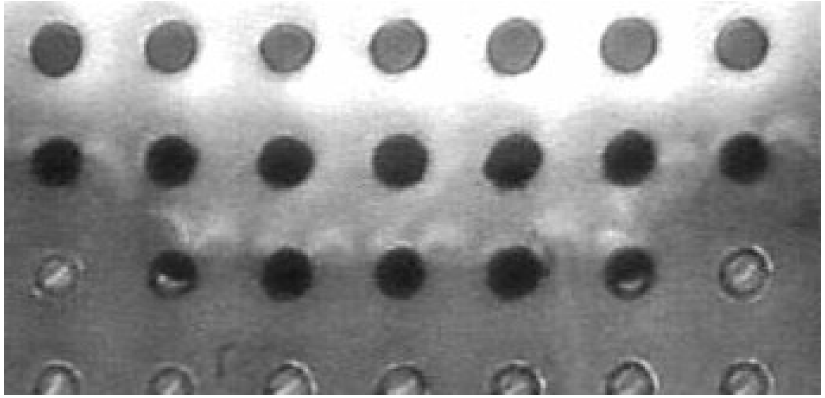


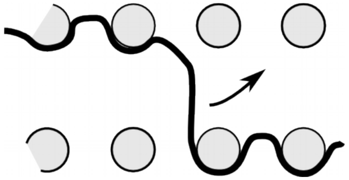


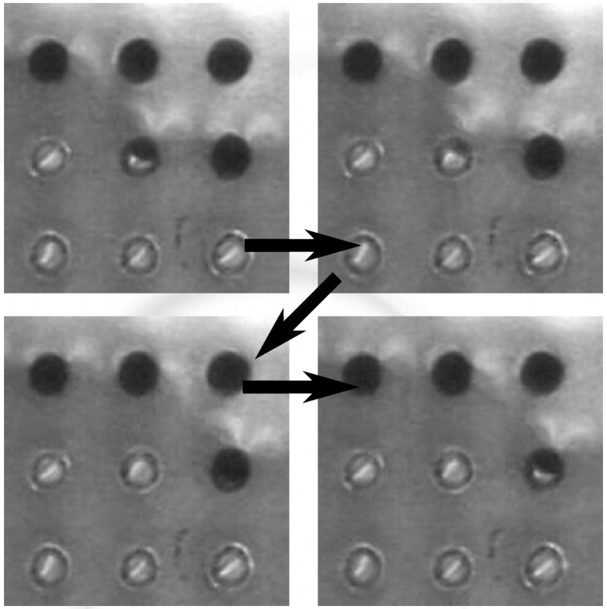
straight

kinked

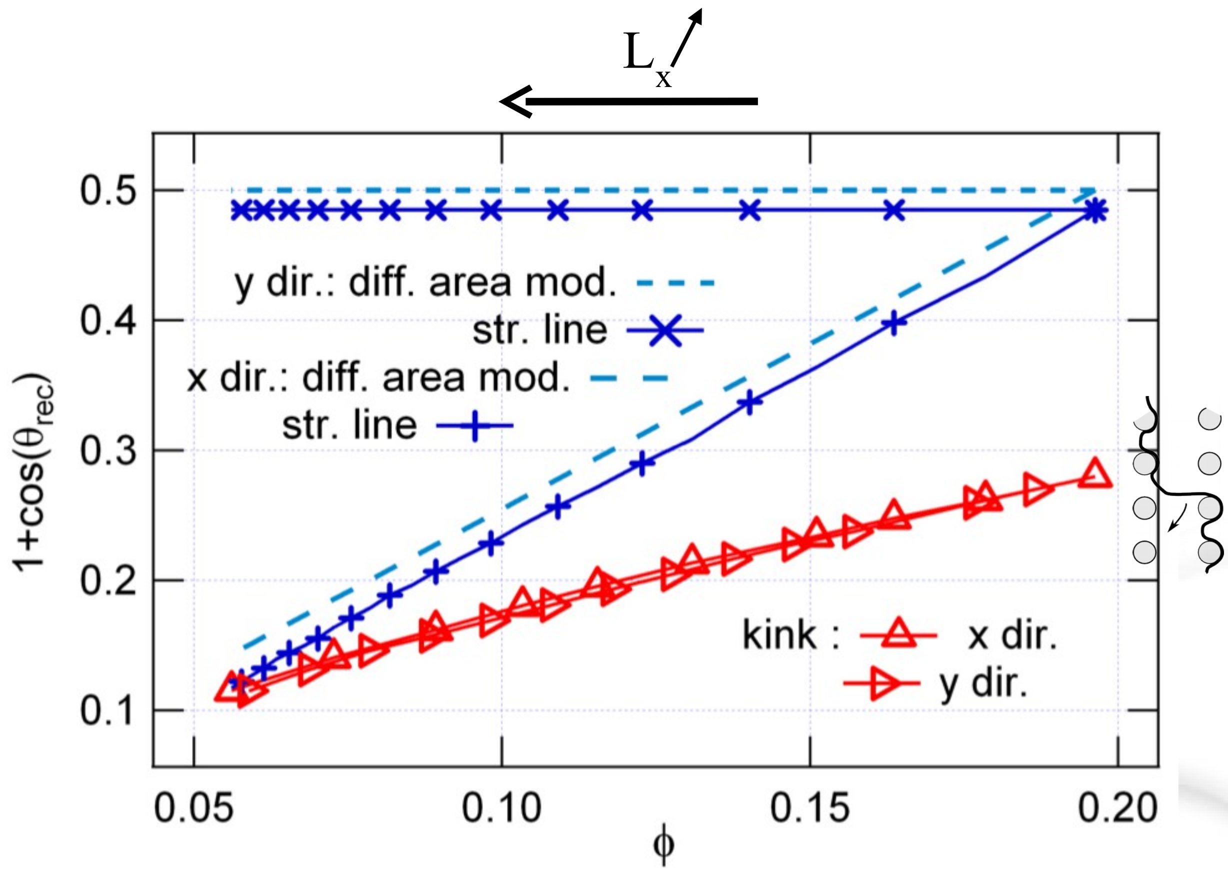


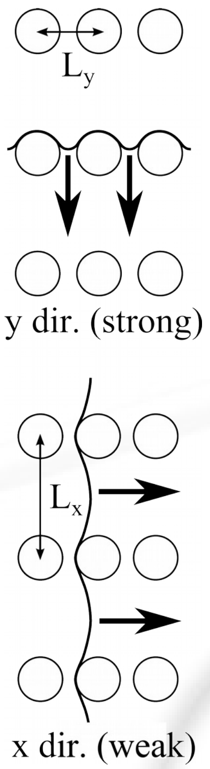






Model – Impact of the kink

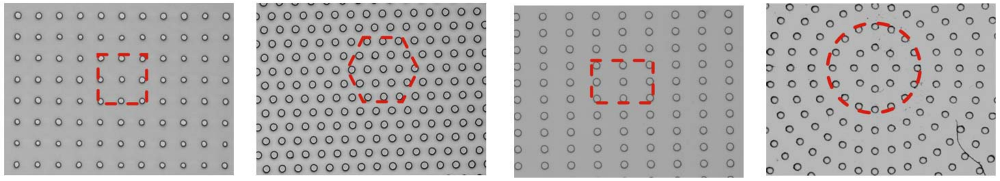


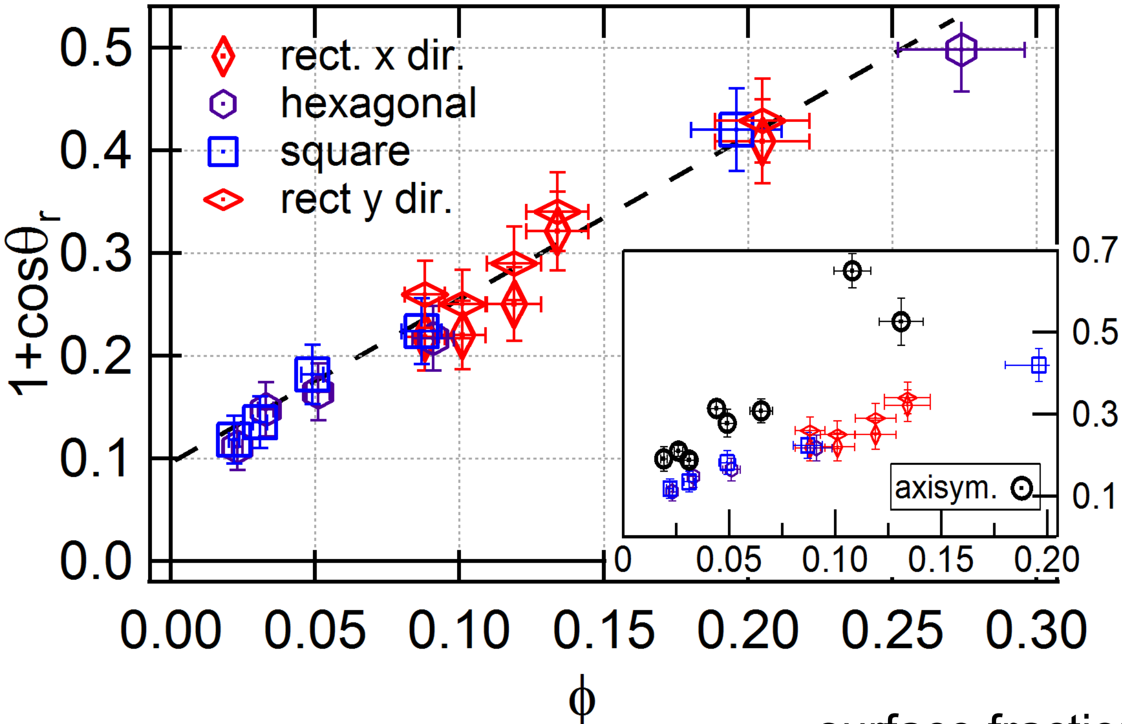


surface fraction

A. Gauthier et al. PRL 2013

Receding contact angle – impact of texture



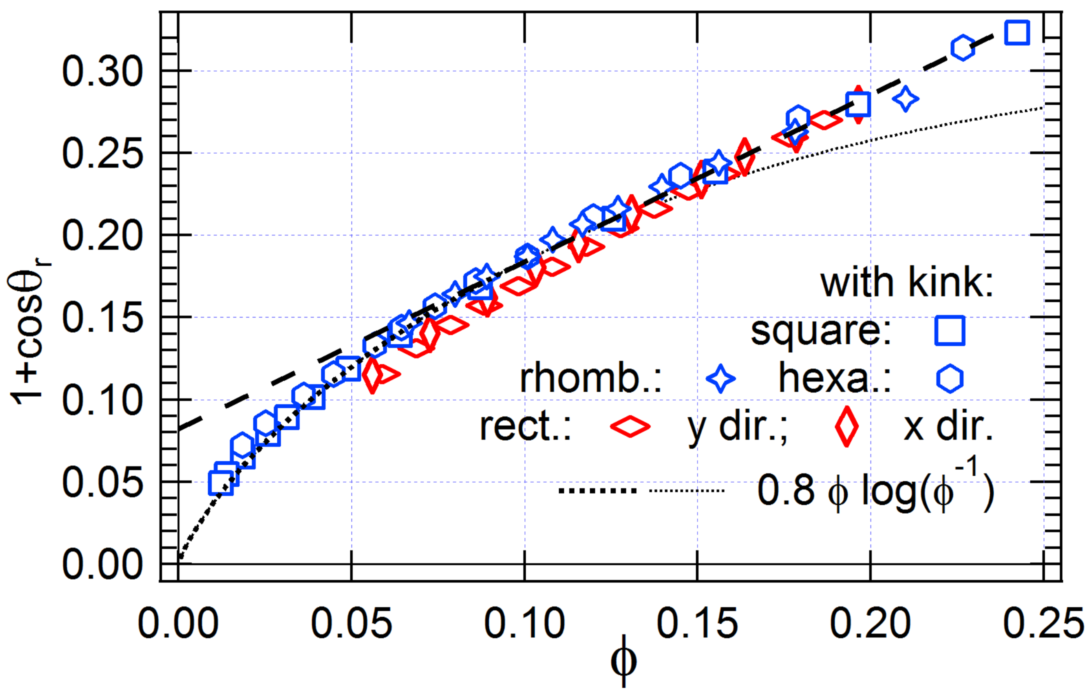


surface fraction

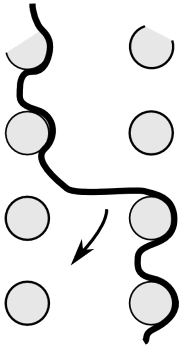
Rivetti et al. PRL 2015

Simulations – receding contact angle

with kink

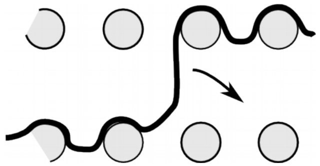


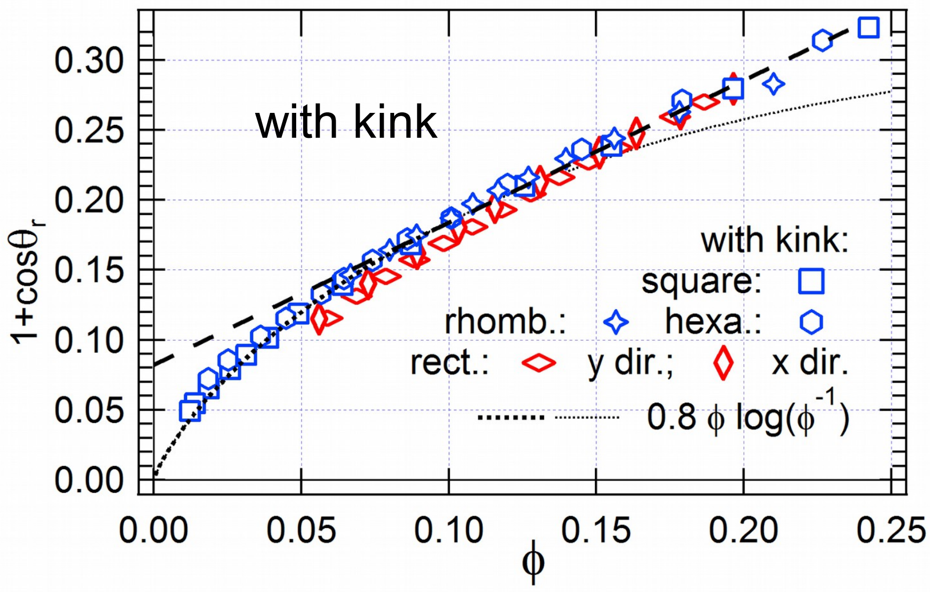
surface fraction

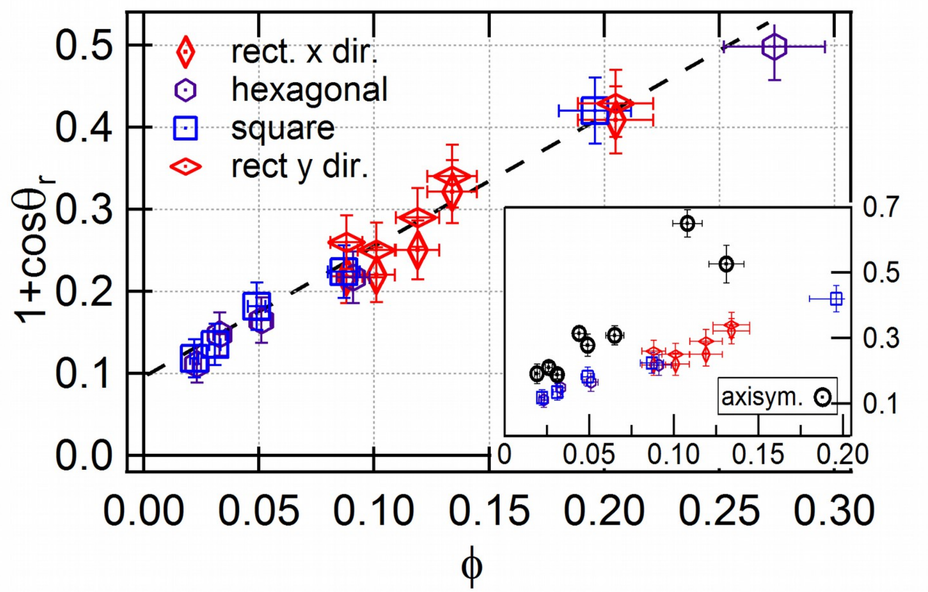


Rivetti et al. PRL 2015

Simulations – data



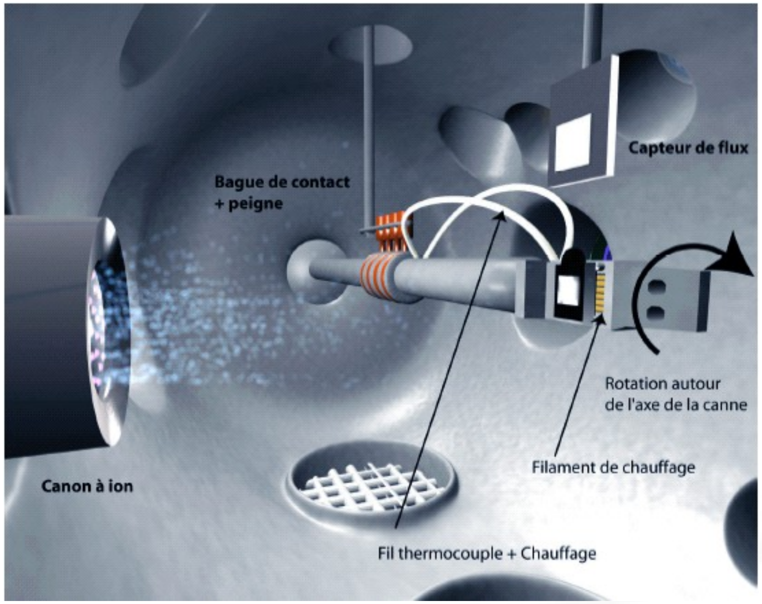


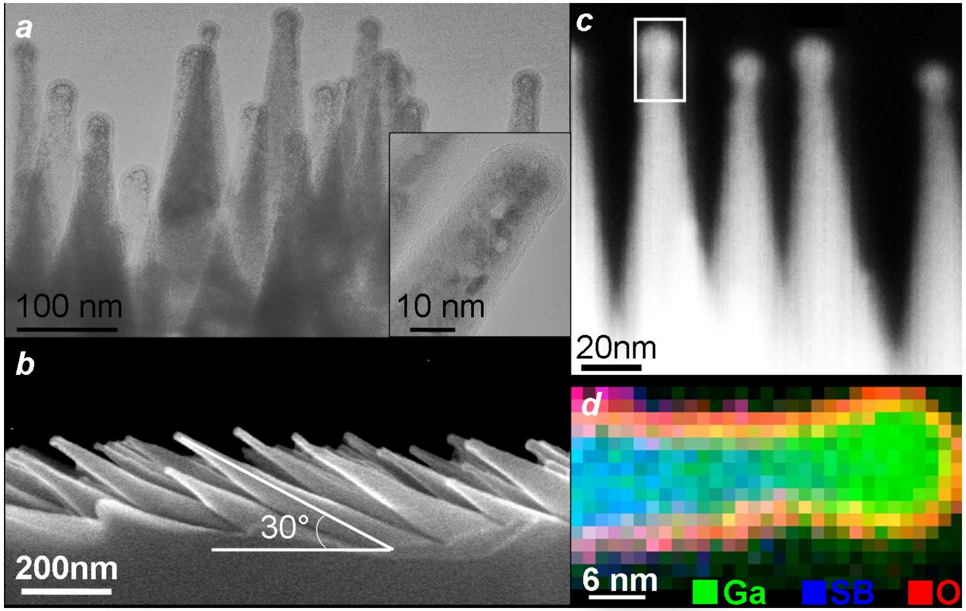


Rivetti et al. PRL 2015

Jansons JFM 1985 (periodic + random)
Joanny & de Gennes J Chem Phys 1984 (random)
Paterson and Fermigier Phys. Fluids 1997
Reyssat and Quéré J. Phys Chem B 2009

Self-organised GaSb structures



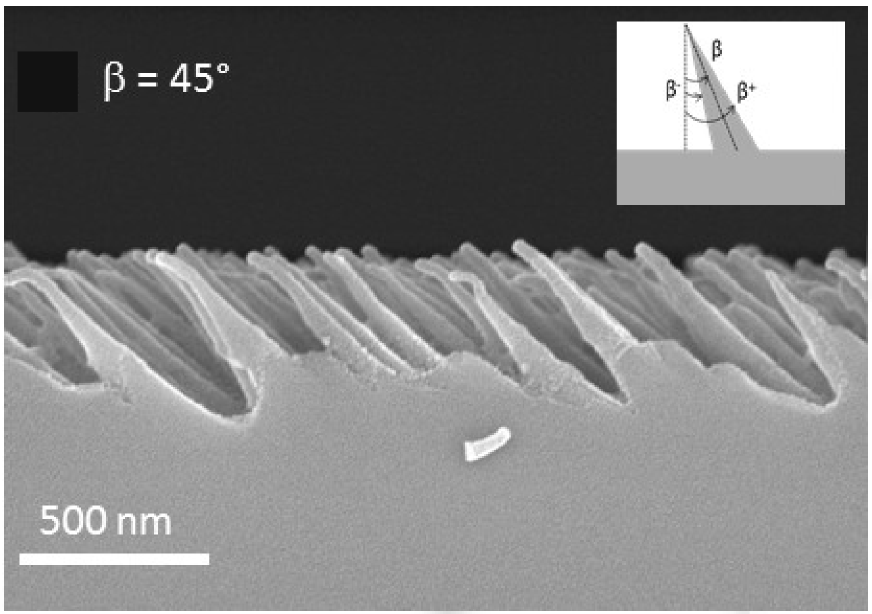


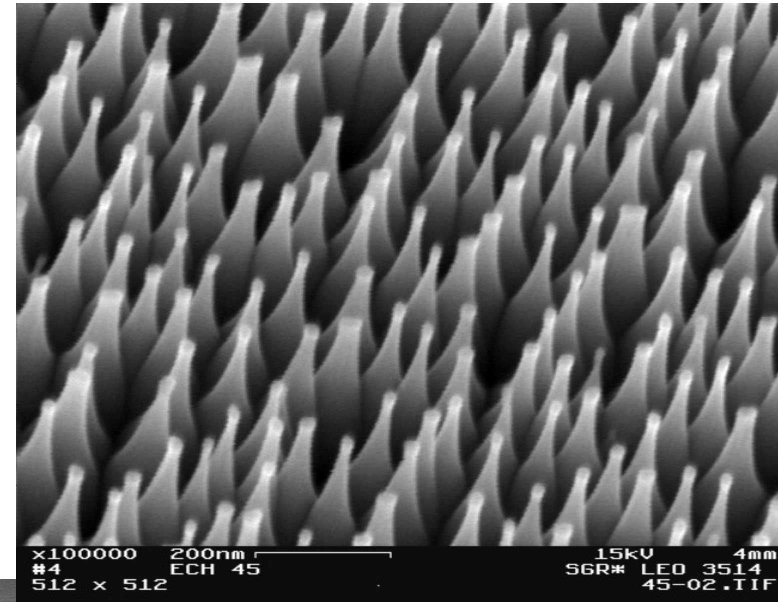
Leroy et al. APL 2009

- GaSb(100) monocrystals
- ion gun
  - Ar^+ plasma
  - 0.1 - 2KeV
  - divergence of 5°

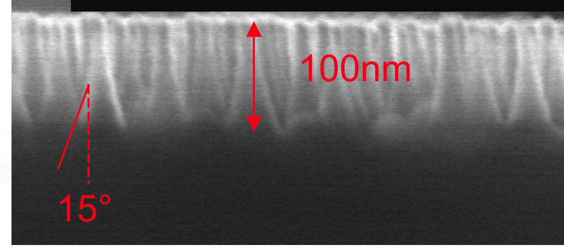
Cone morphologies
straight vs. tilted

inclination angle β



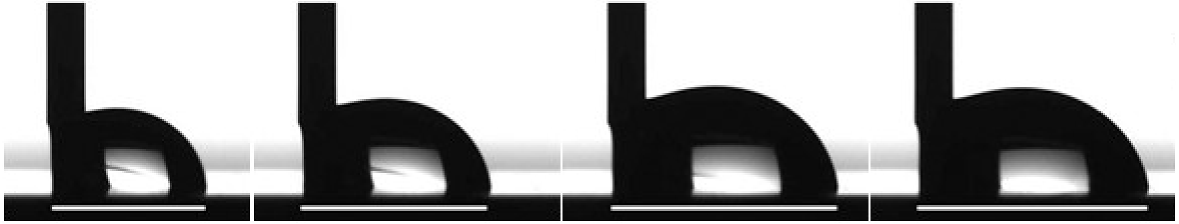


9 min, 500 eV, 0.03mA/s cm2

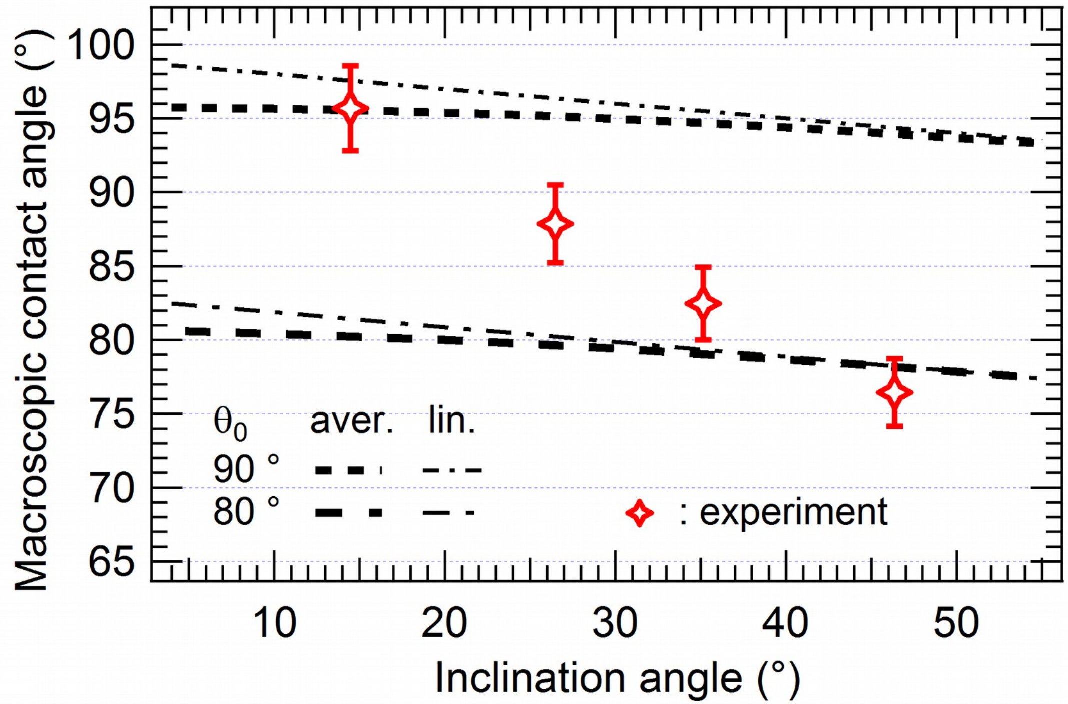


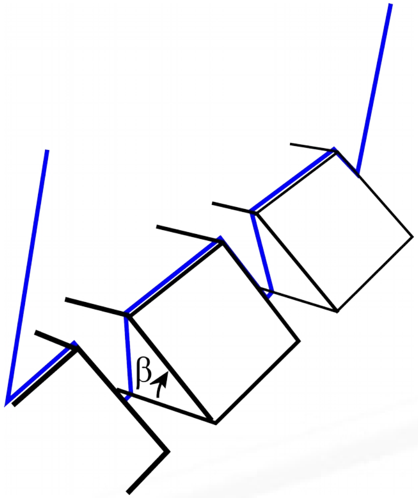
Leroy et al. APL 2009

Advancing contact angle – tilted cones

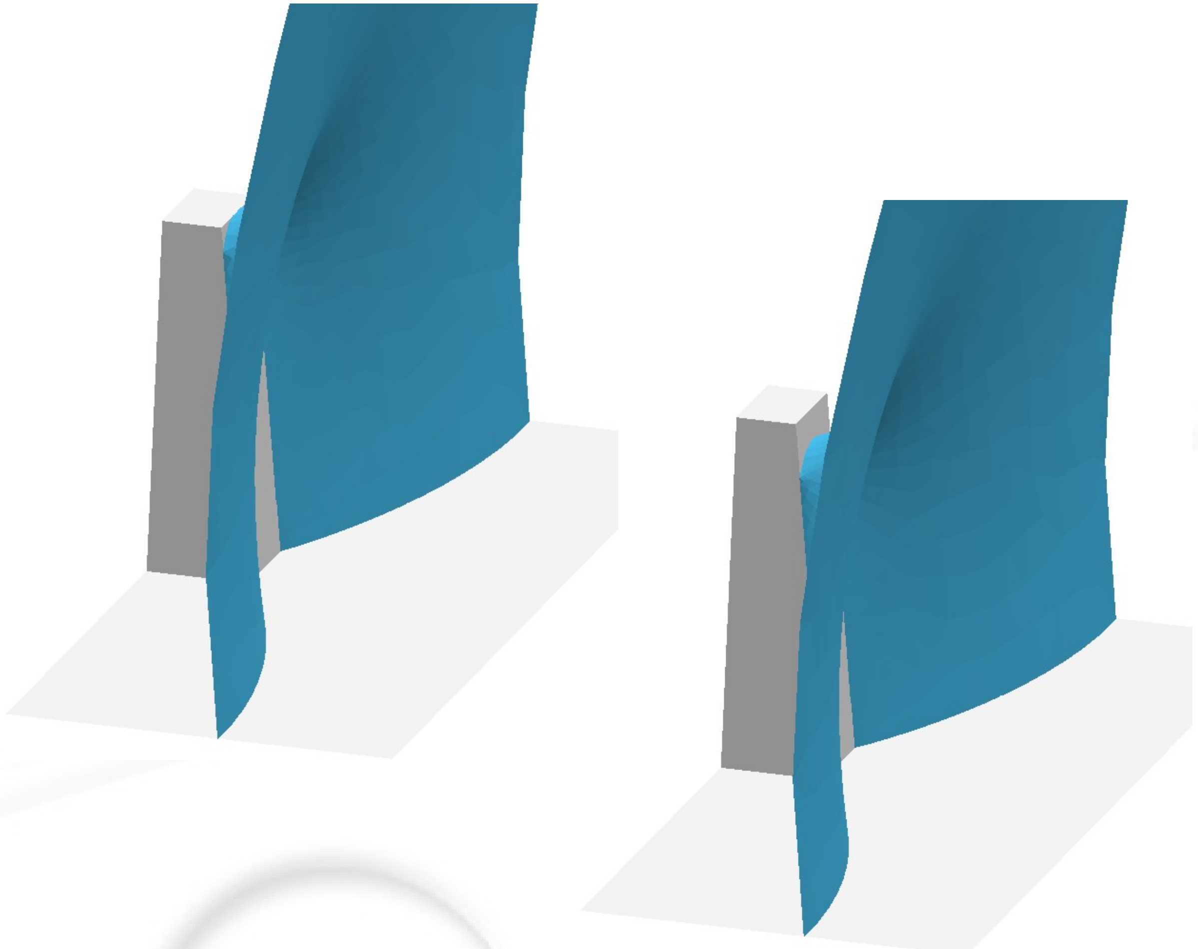


Advancing contact angle *vs.* inclination



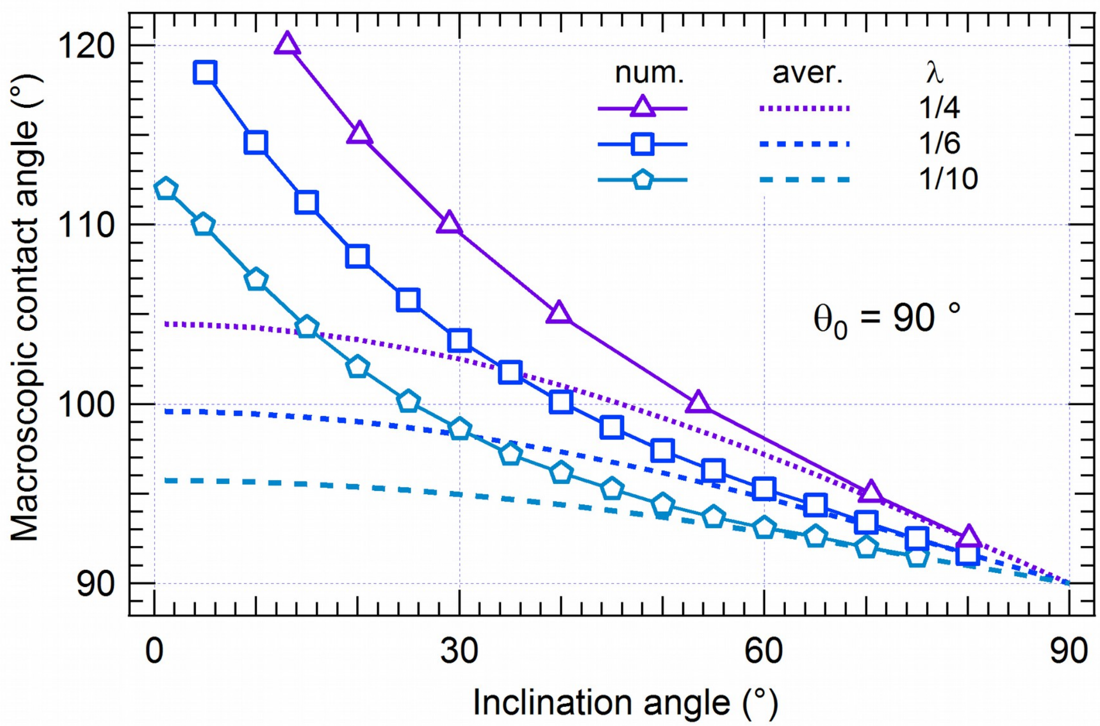


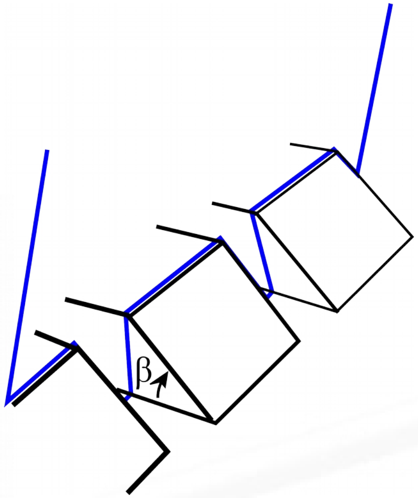
Advancing contact angle as depinning threshold



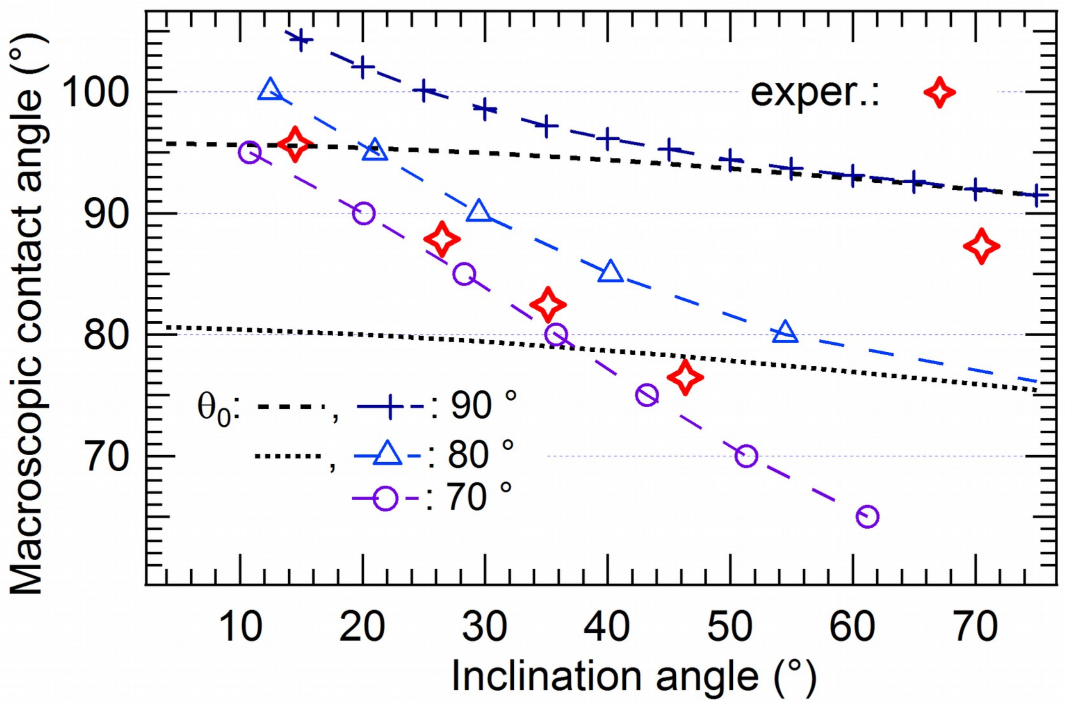
Advancing contact angle - Predictions

Impact of depinning





Advancing contact angle - Data
impact of pinning



E. Contraire et al., Soft Matter 2016

Conclusion

- Wetting on textured hydrophobic surfaces
  - triple line pinning
  - elasticity
- Impact of order
  - kink
  - reduction of depinning stress