Engineering Dewetted Surfaces and Colloidal Deposits via a Droplet Deposition on a Solid Surface

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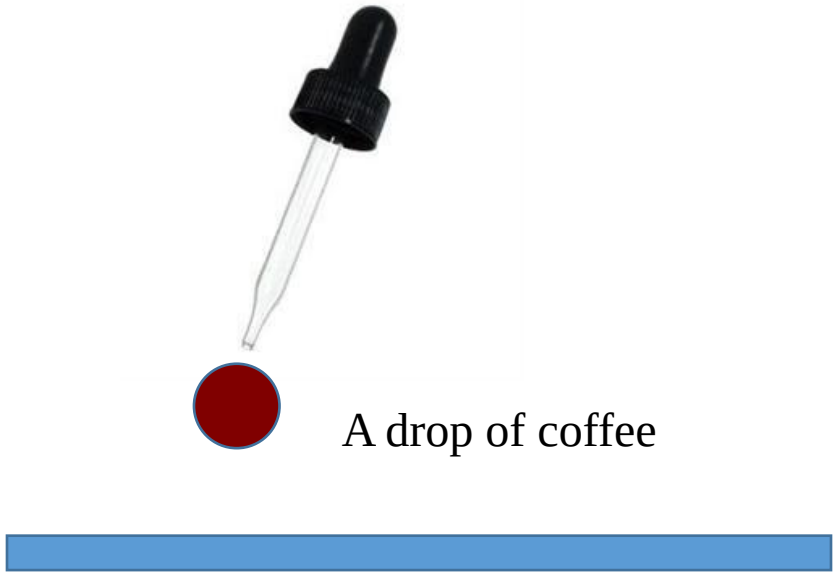
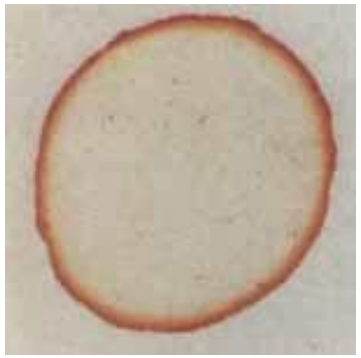
Institute Award Lecture Series -2017

Image taken by M. Kumar

A simple lab (or office) experiment

Winerist.com

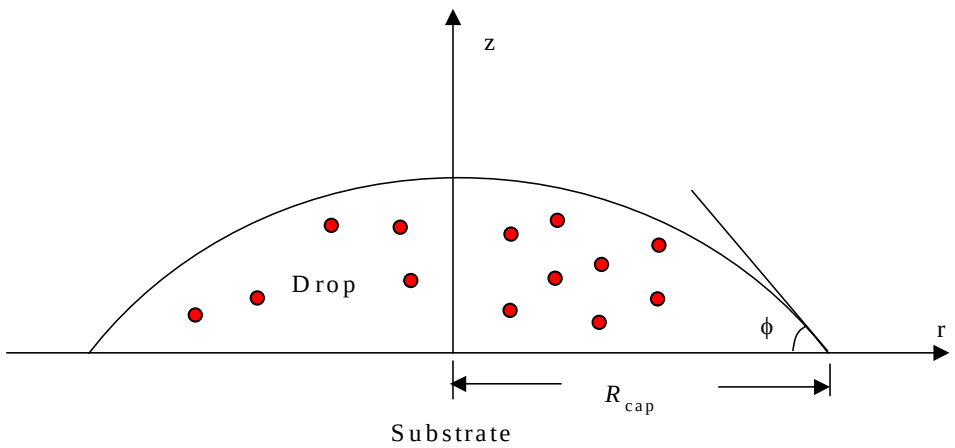


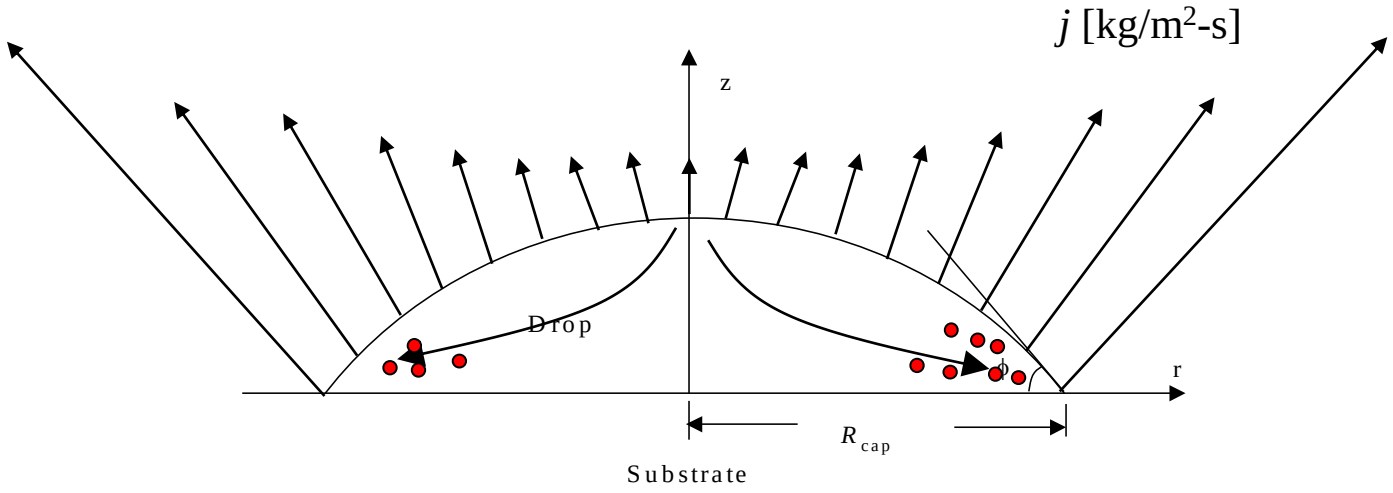


Deegan et al.

Dried deposit obtained on solid surface

“Coffee-ring problem”

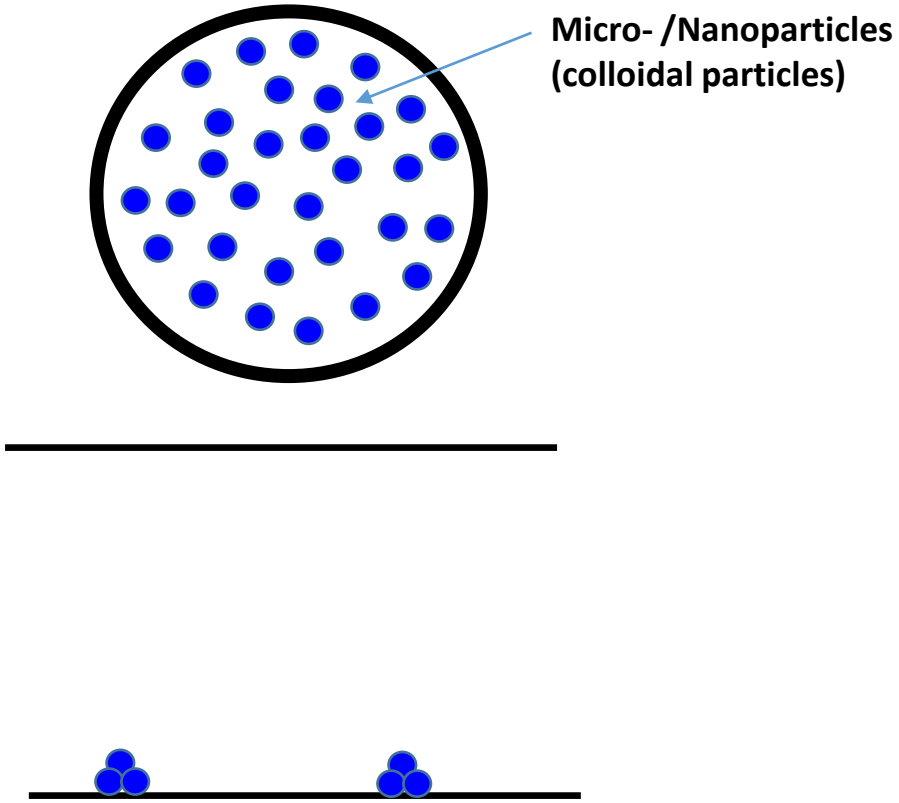


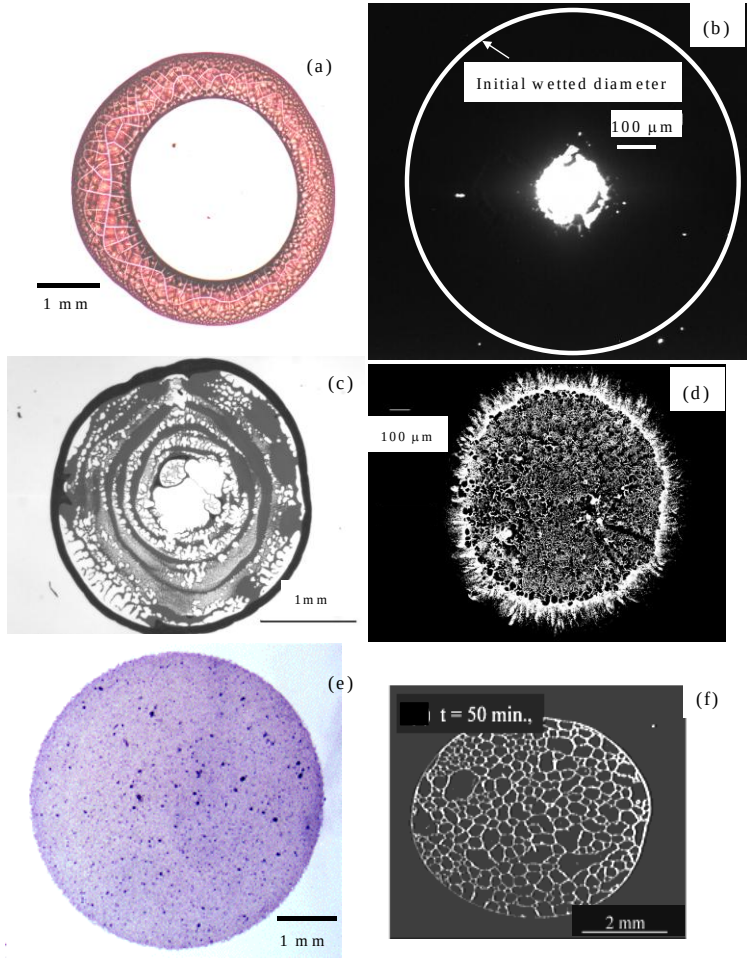


First explained by Deegan et al., Nature, 1997

- **Is formation of ring universal to such systems?**
- **If not, can we control the deposition of particles by leveraging complex and coupled transport phenomena inside the evaporating droplet?**

Motivation: Colloidal deposits





(a) Ring like pattern (Sommer et al, 2004)
(b) Central bump (Bhardwaj et al., 2009)
(c) Multiple ring patterns (Bhardwaj, unpublished)
(d) Fingering at wetting line (Bhardwaj, unpublished)
(e) Uniform deposition pattern (Sommer, 2004)
(f) Hexagonal cells (Truskett and Stebe, 2003)

A zoomed-in view of a part of the ring

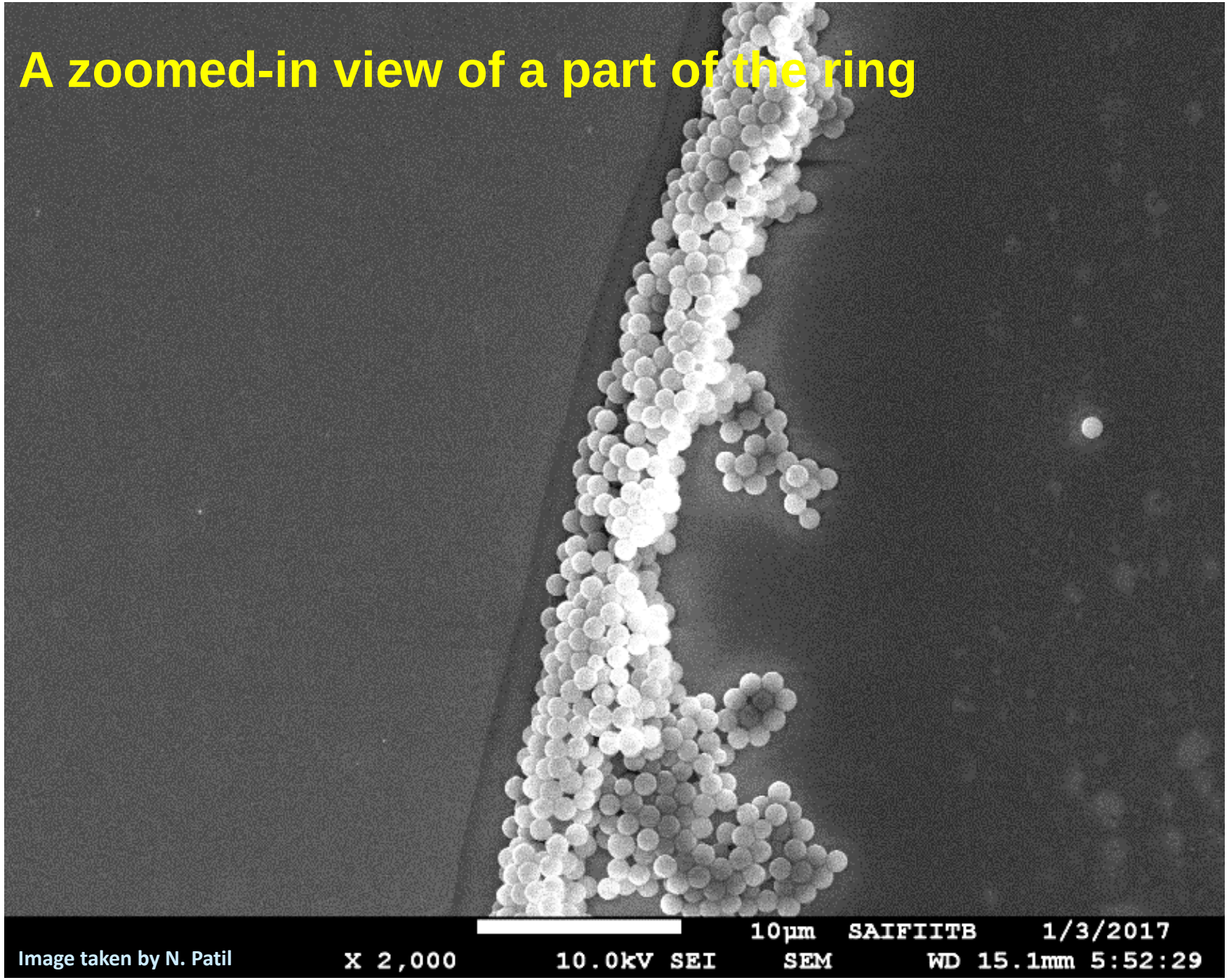
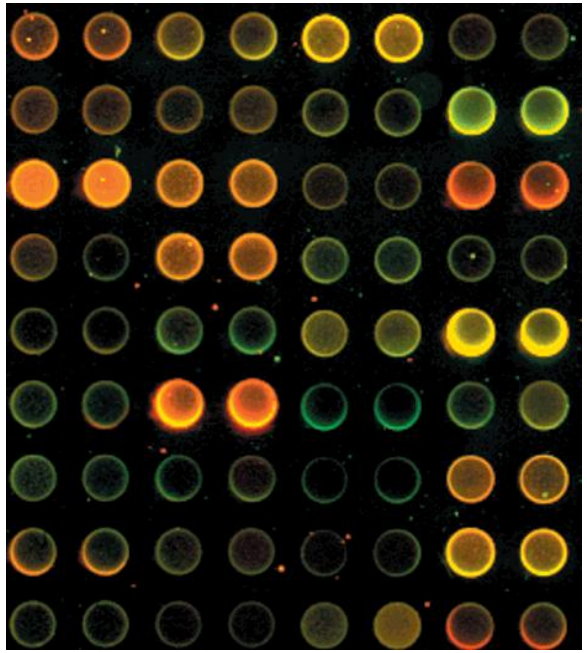


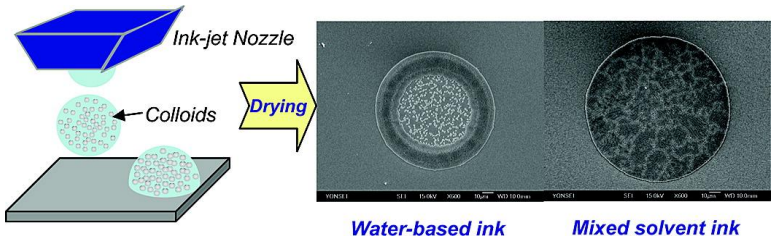
Image taken by N. Patil

Technical applications of the deposits

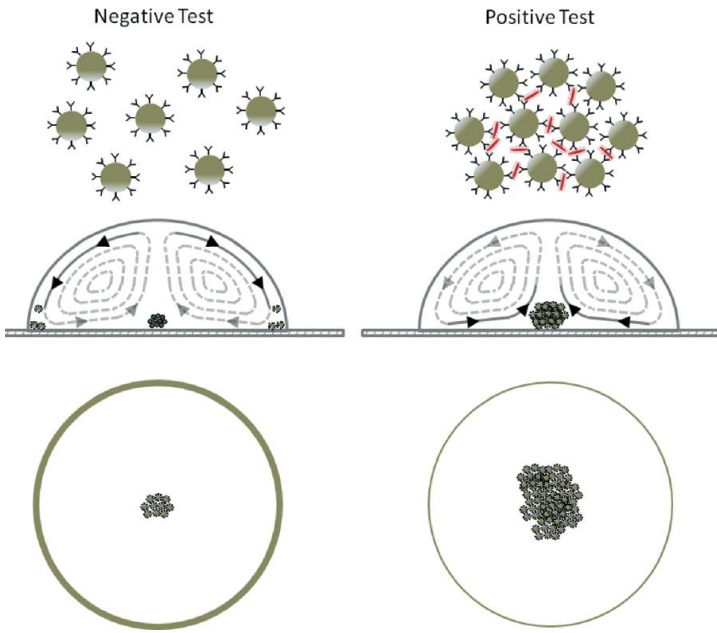
Bioassays, inkjet printing, particles sorting, colloidal crystals for photonics



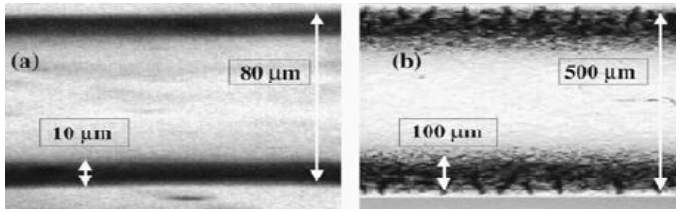
Biomarkers
Blossey and Bosio, 2002



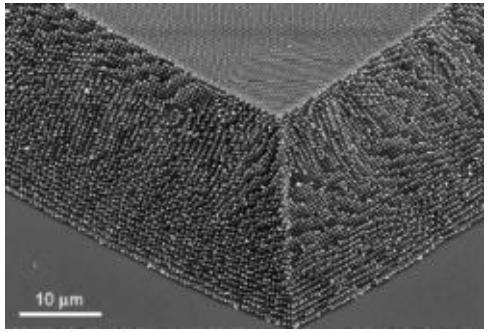
Park and Moon, Langmuir, 2006



Biosensors,
Trantum et al., 2014



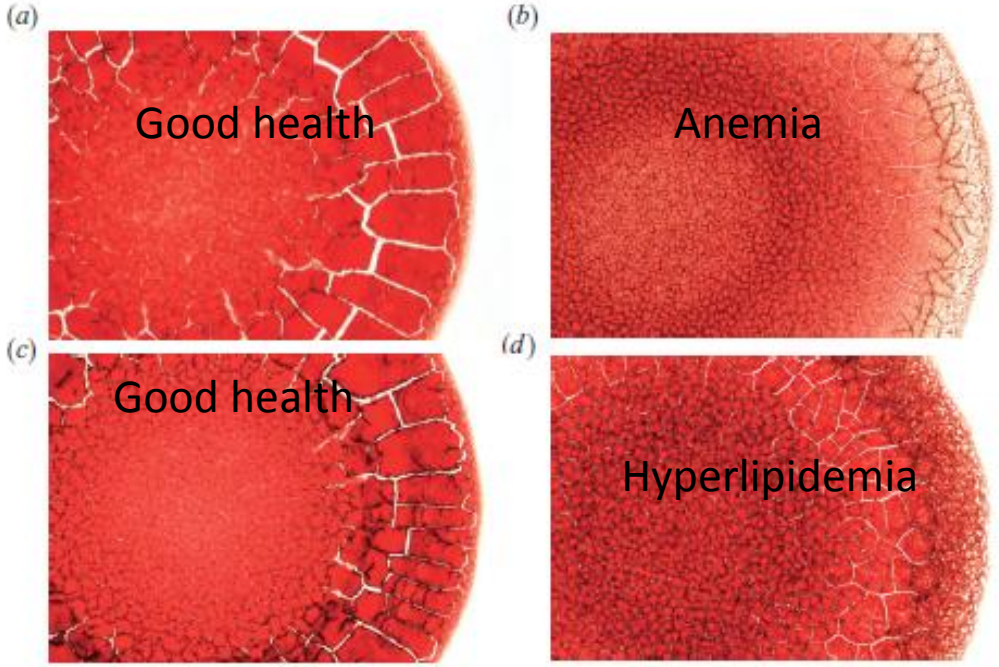
Cuk et al., App. Phys. Lett. 2000



Photonic colloidal crystals,
Jiang group, Univ. Florida

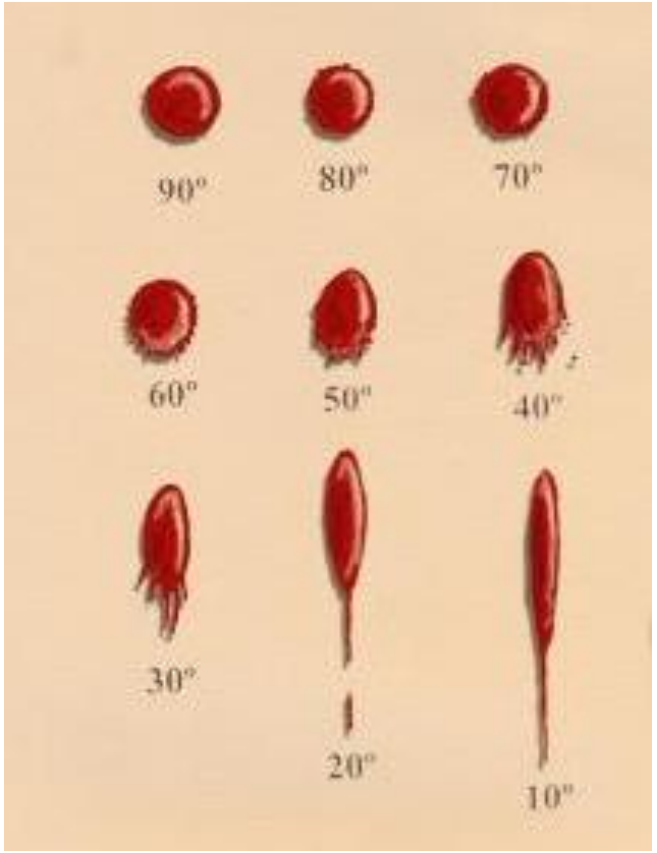
Dried droplets of blood

Biomarkers



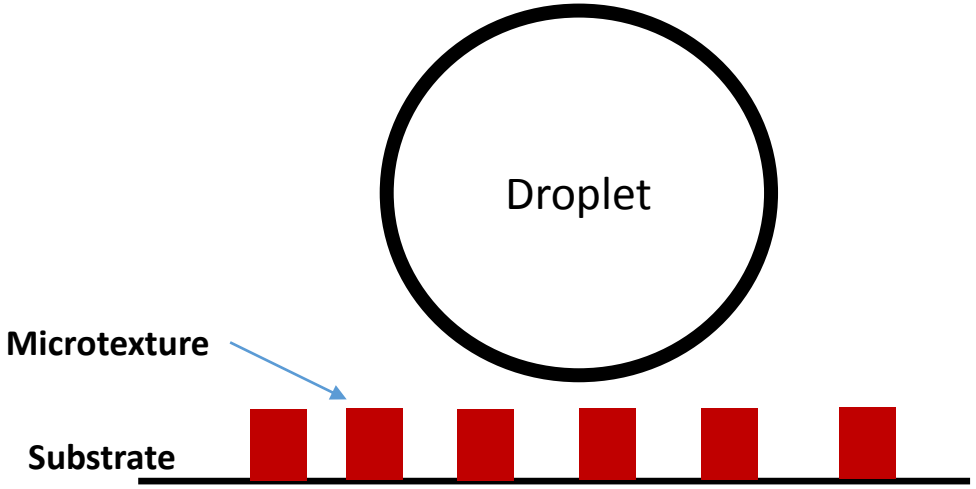
Brutin et al, 2011

Forensics (BPA)



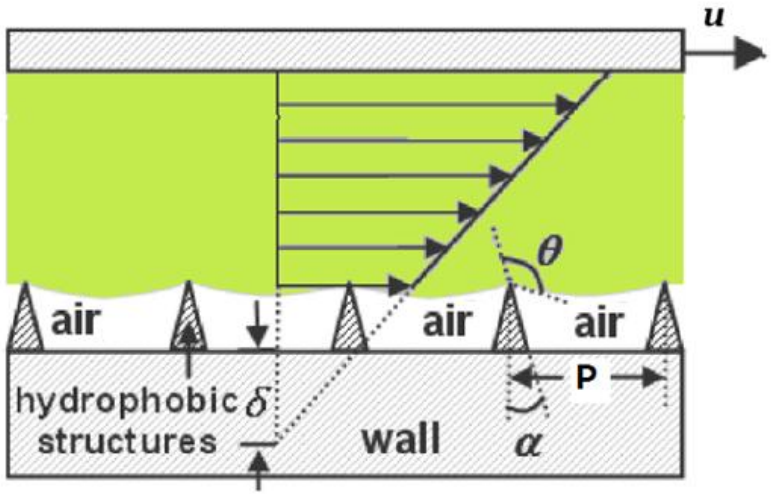
Crimeforensics-scene.com

Motivation: Dewetted surfaces



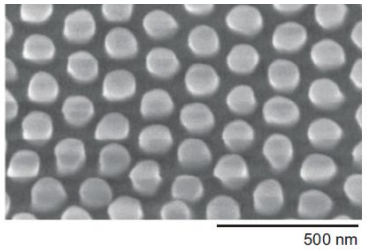
- Self-cleaning, antifouling, anti-icing, low-drag surfaces

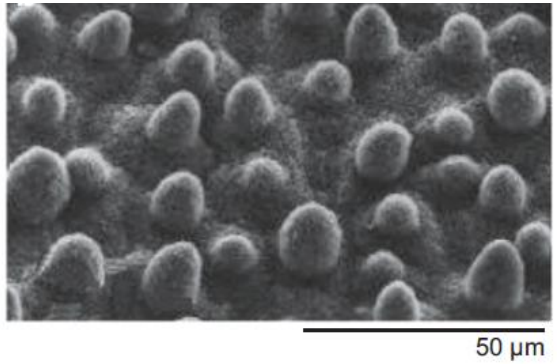
Scientific American, 2008



Dewetted surfaces in nature

Gao et al., 2007





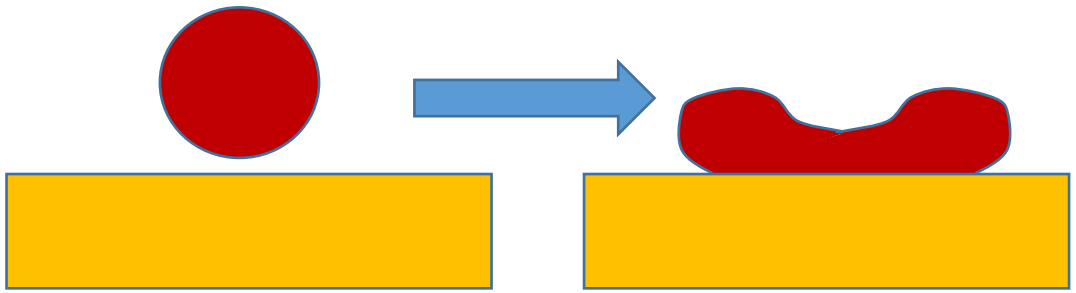
Ensikat et al., 2011

Bush et al., 2008

Coupled physics

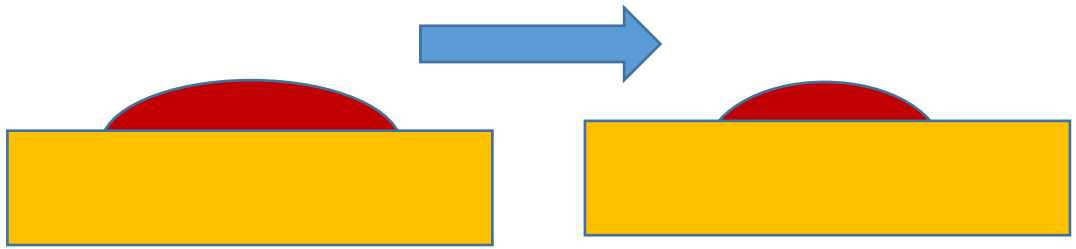
Impact

micro-/miliseconds



Evaporation

seconds/minutes

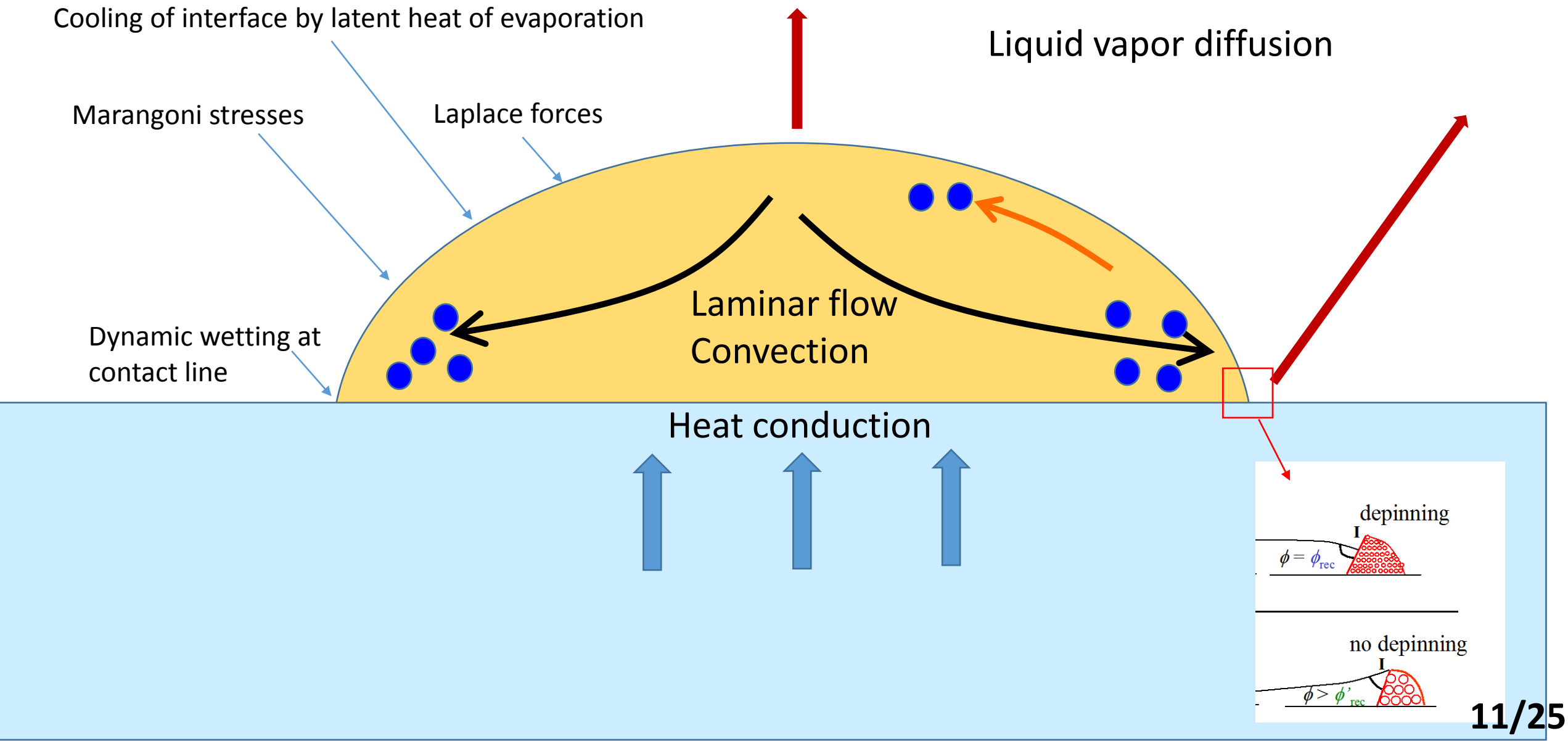


Time scales as diameter/velocity

1 mm droplet
1 m/s impact velocity
Spreading time ~ 1 ms

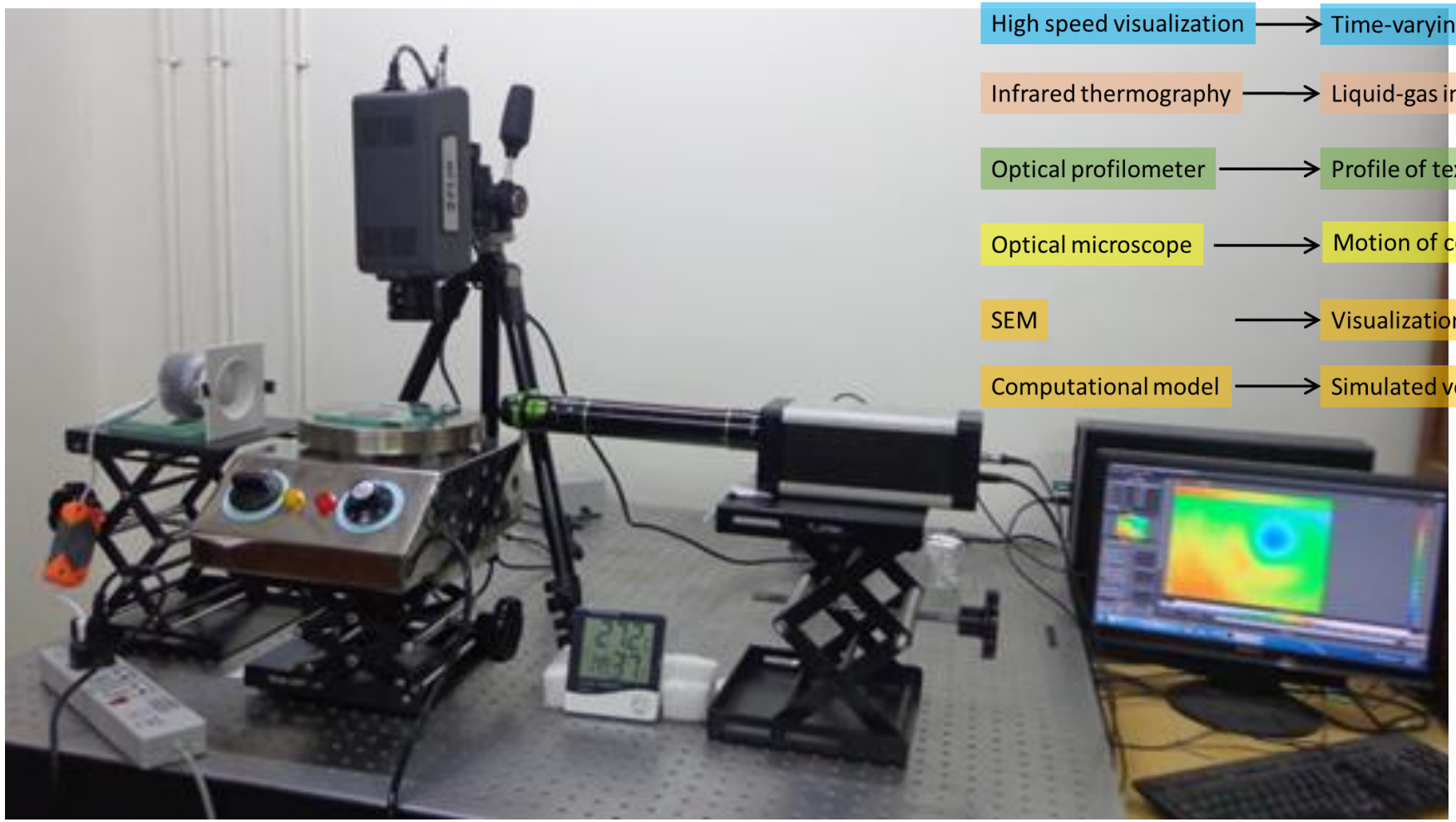
Blinking time of human eye ~ 200 ms

Classical transport of mass, momentum and heat

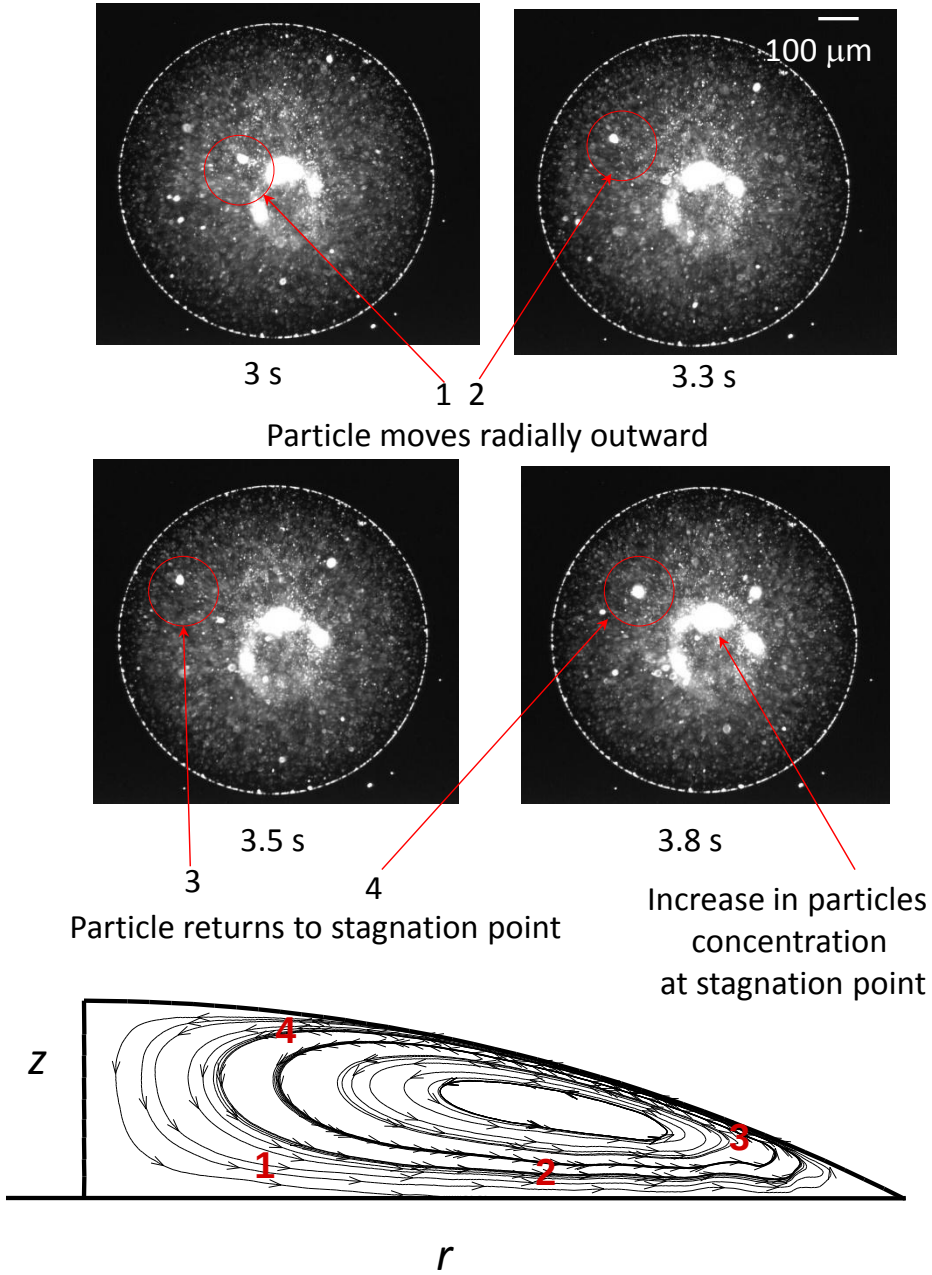


Methods

Methods	Outcome/Data to be collected
Photolithography →	Manufacturing of textured surfaces
High speed visualization →	Time-varying droplet shapes
Infrared thermography →	Liquid-gas interface temperature field
Optical profilometer →	Profile of textured surface/Deposit dimension
Optical microscope →	Motion of colloidal particles
SEM →	Visualization of colloidal deposits
Computational model →	Simulated velocity and temperature field



Role of Marangoni convection

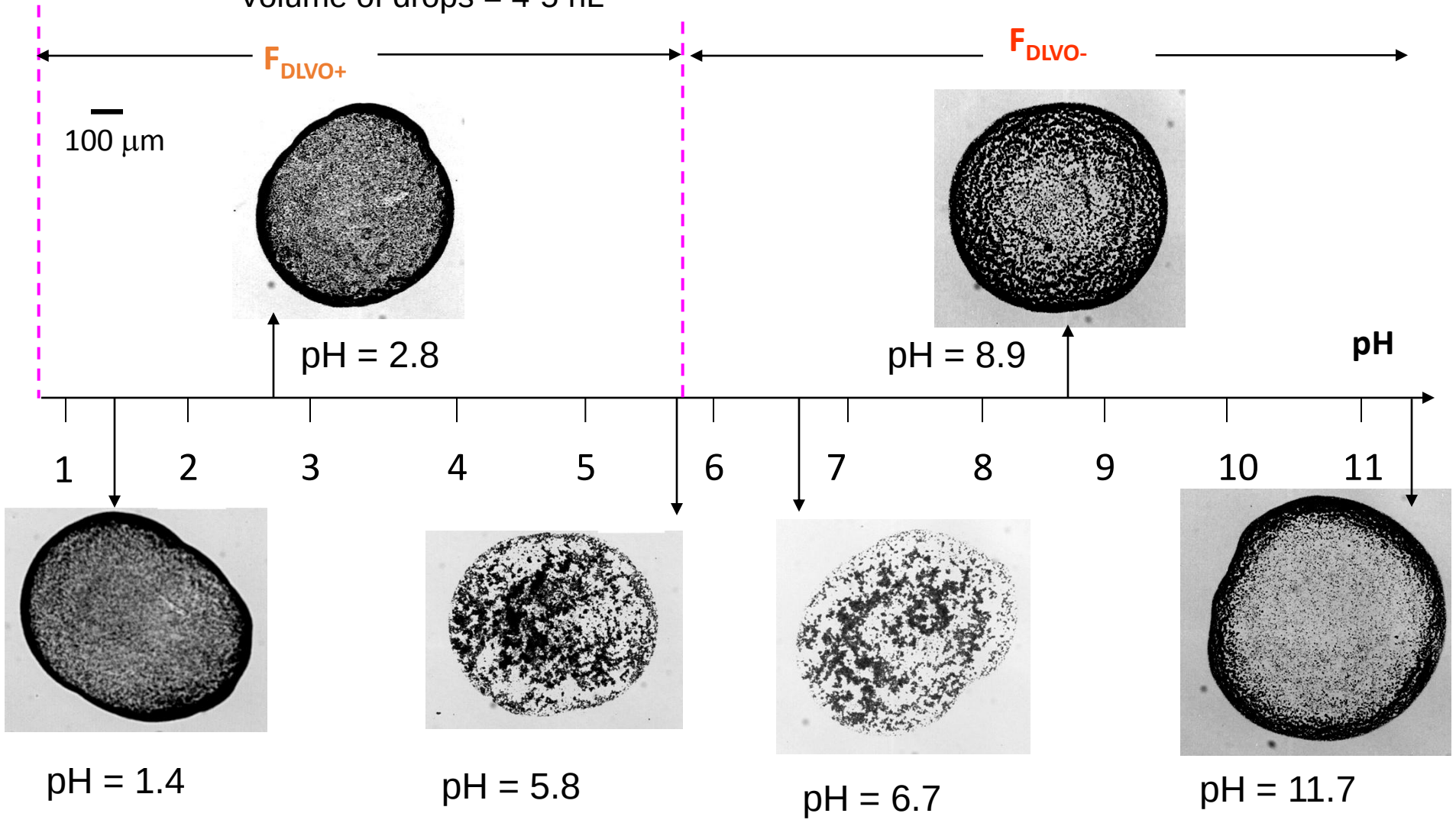


Bhardwaj, Fang, Attinger., New. J. Phys, 2009

Uniform deposit formation: Influence of DLVO interactions

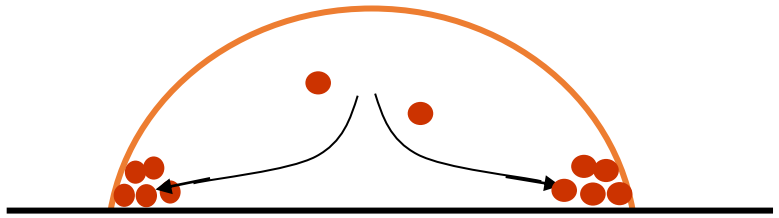
System: Water-glass-air-titania
Parameters: Diameter of particles = 25 nm,
particles concentration = 2%
Volume of drops = 4-5 nL

Bhardwaj, Fang, Som, Attinger., Langmuir, 2010

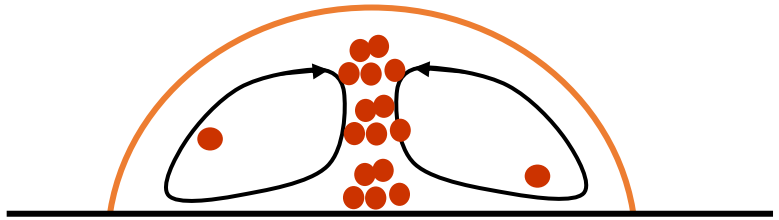


Regime map

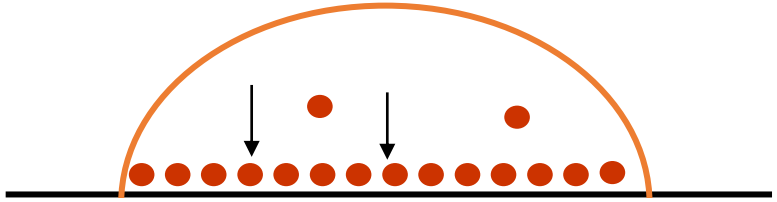
Radial flow driven by evaporation

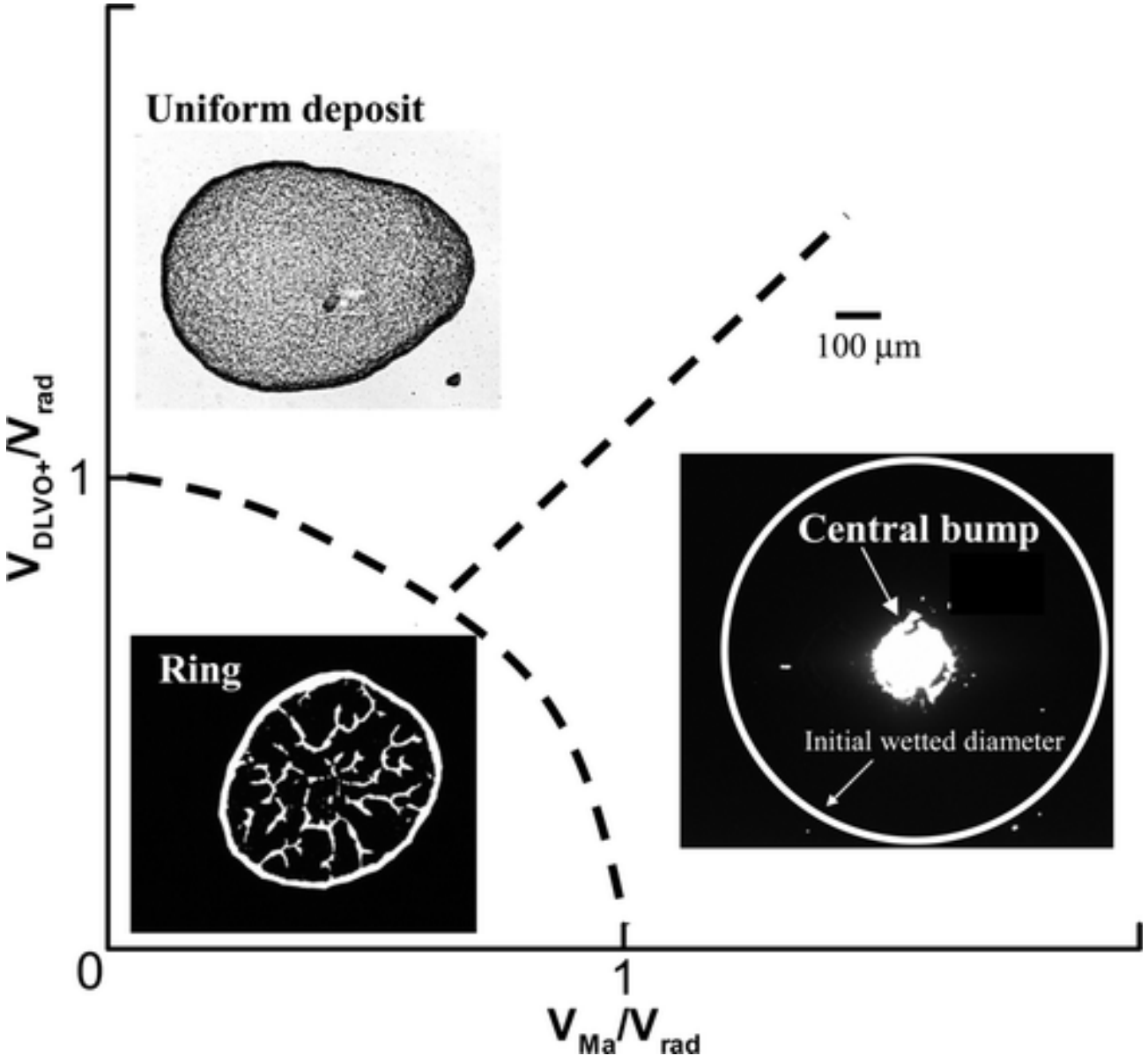


Marangoni recirculation



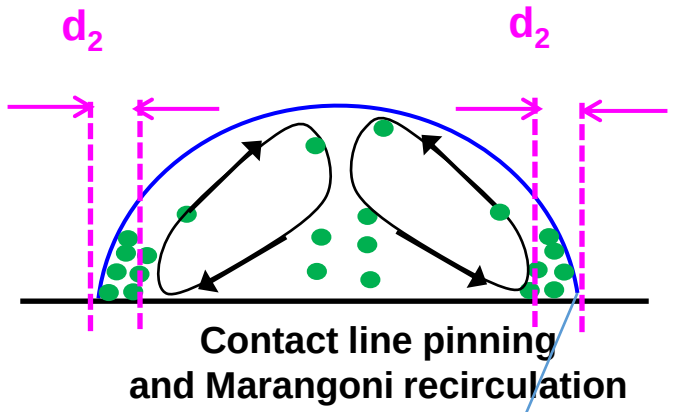
Attractive DLVO force

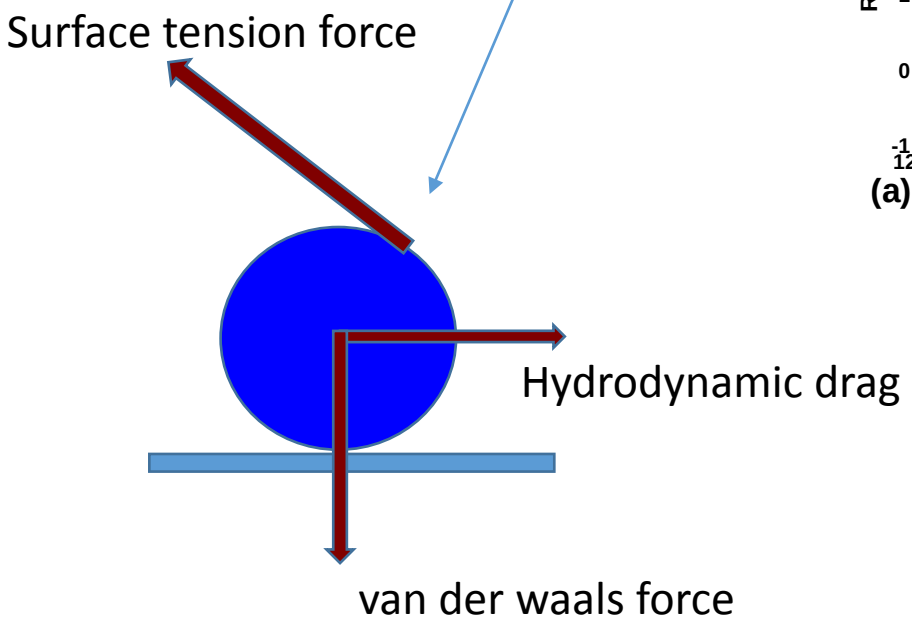


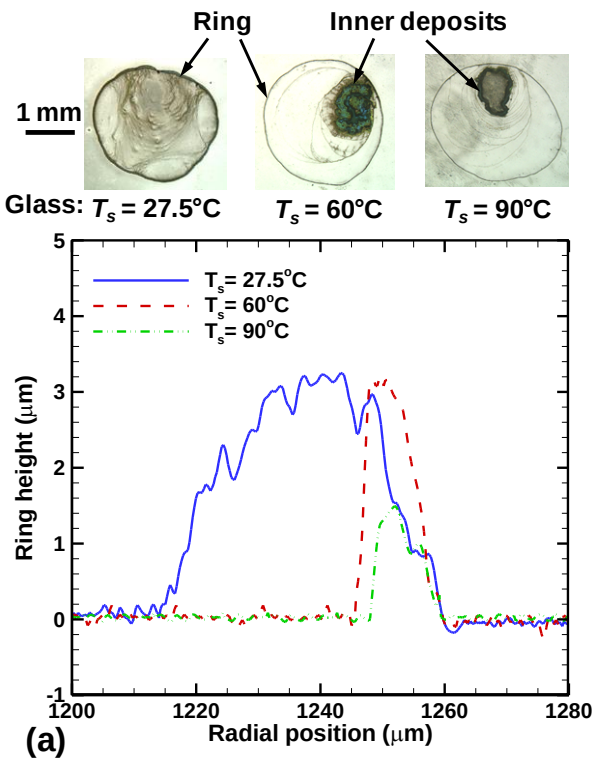


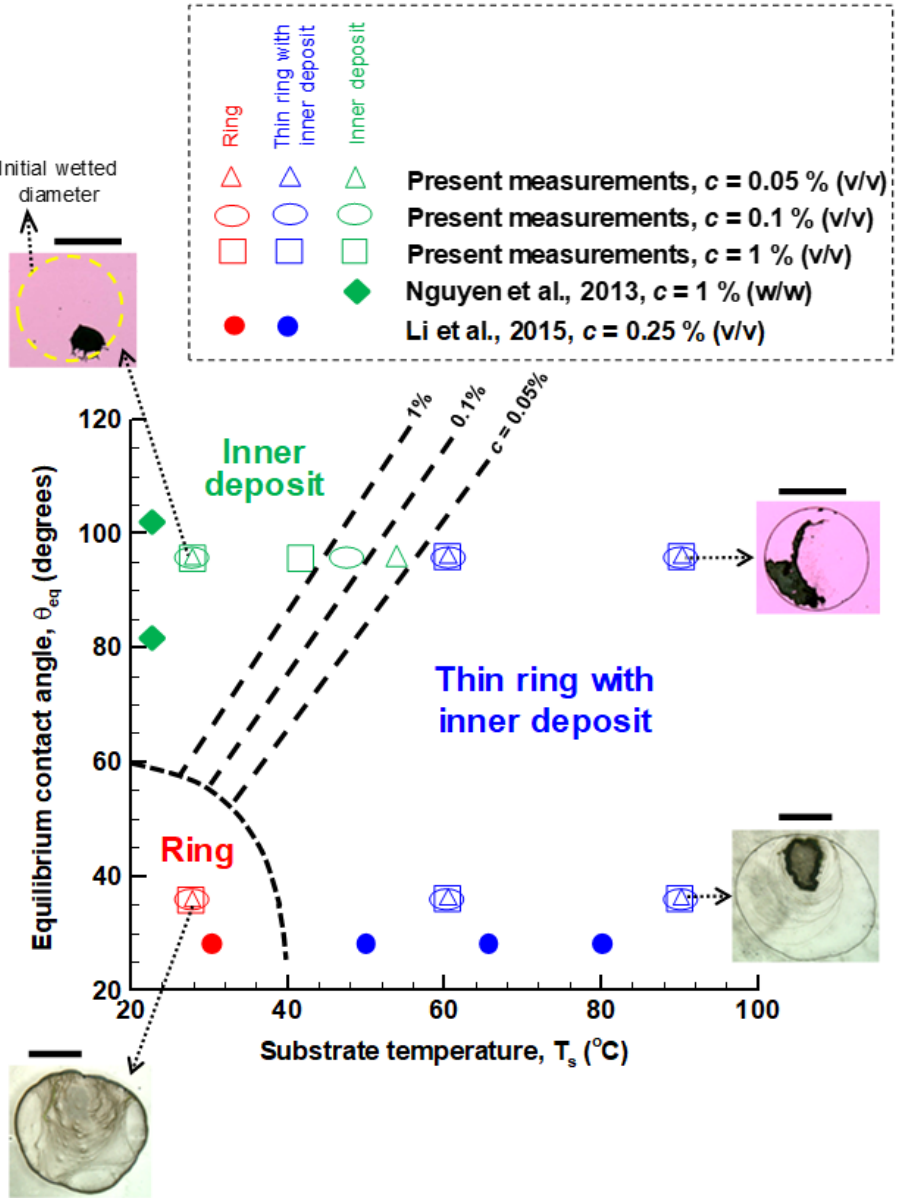
Role of Substrate heating

Patil, Bhardwaj , Sharma, Langmuir, 2016

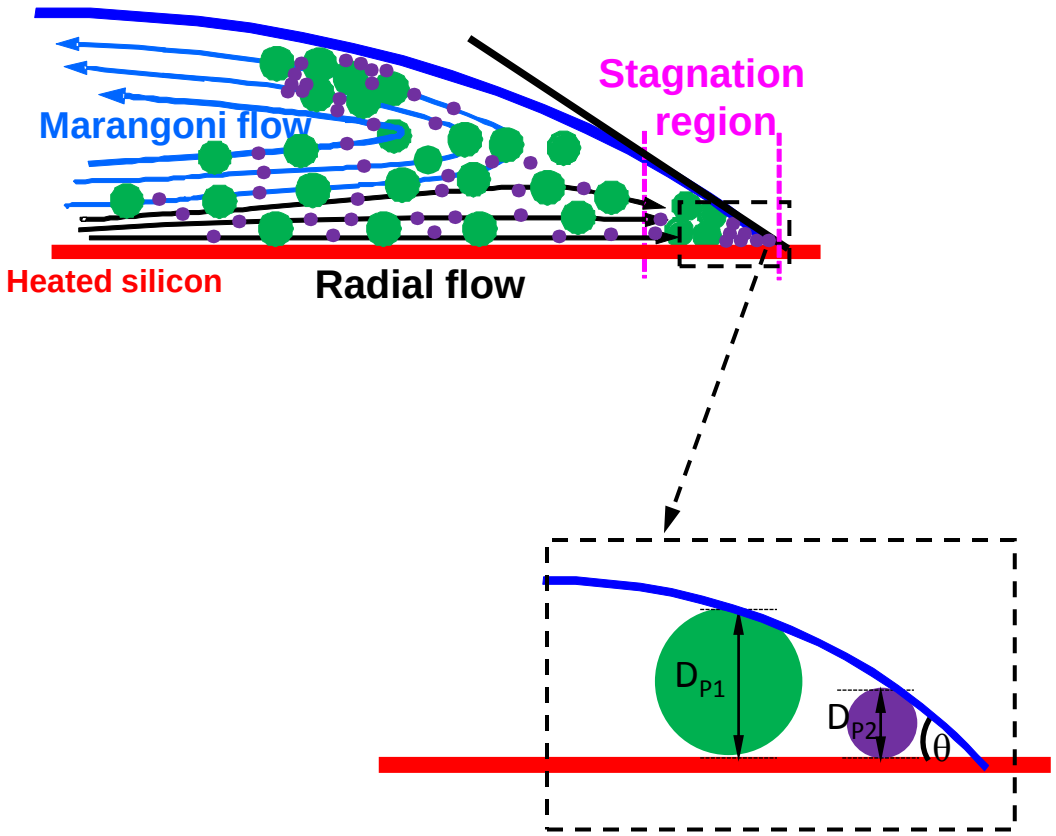


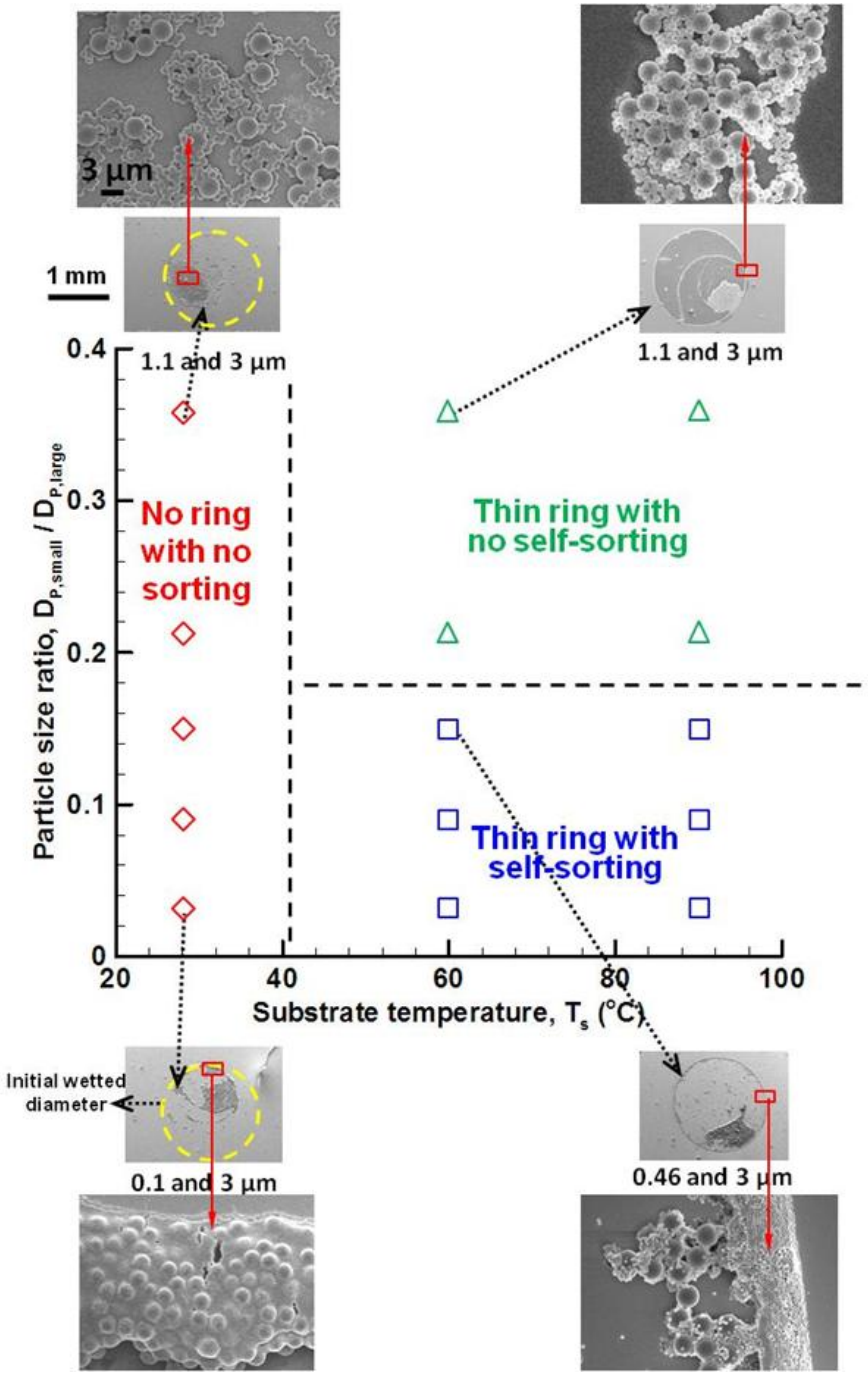






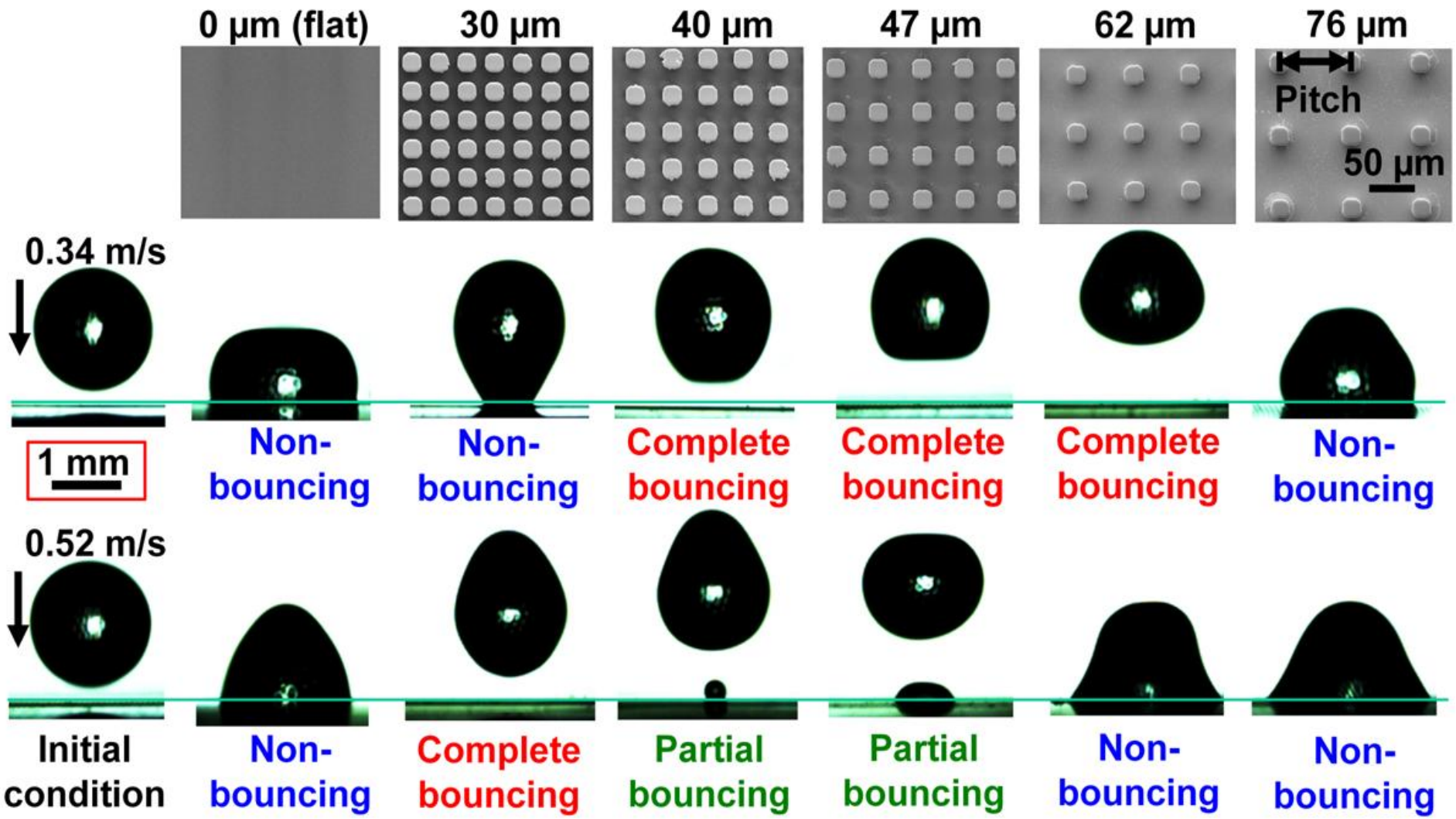
Self-sorting of particles





Patil, Bhardwaj , Sharma, to be submitted

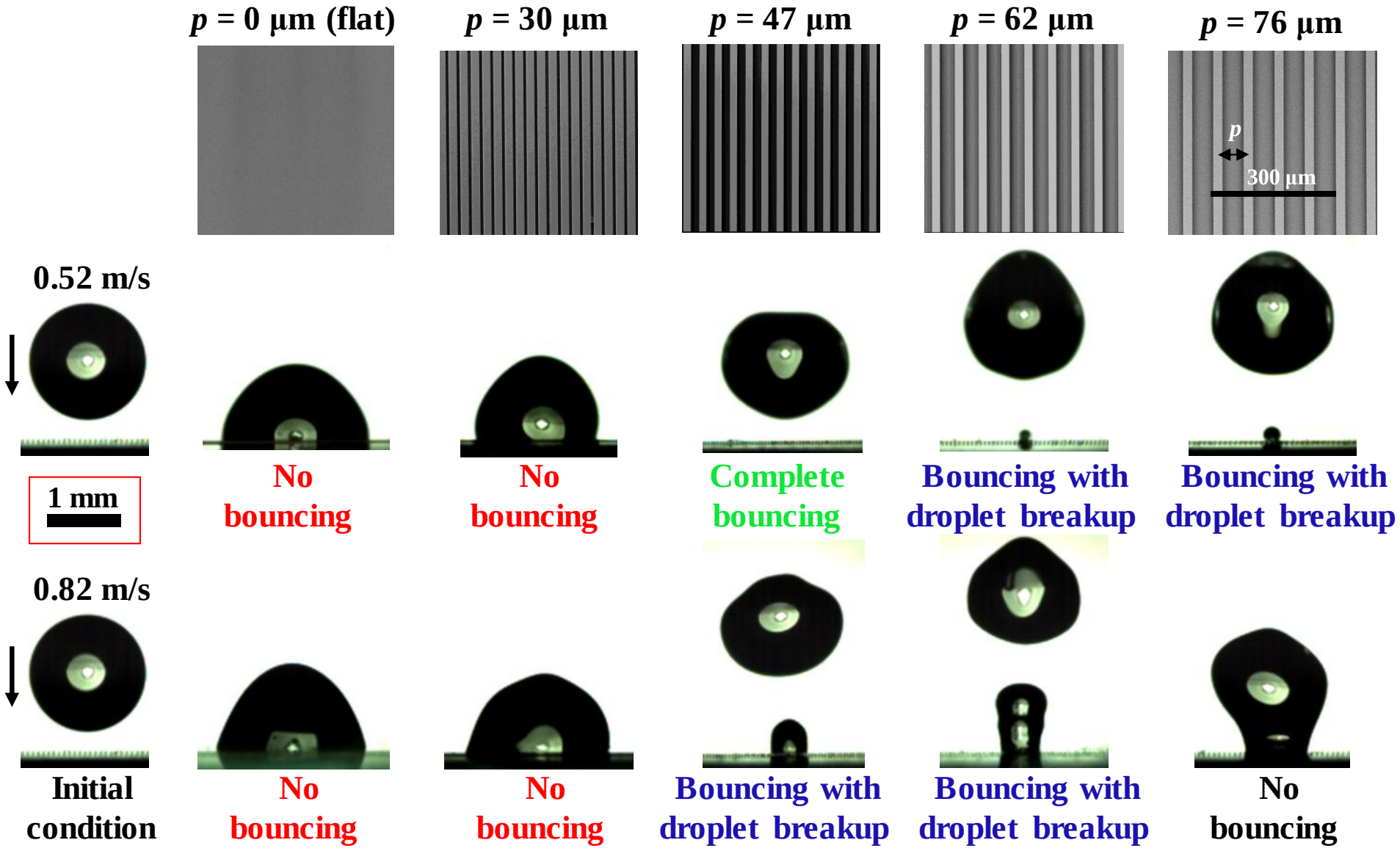
Pure liquid droplet impact on microtextured surfaces



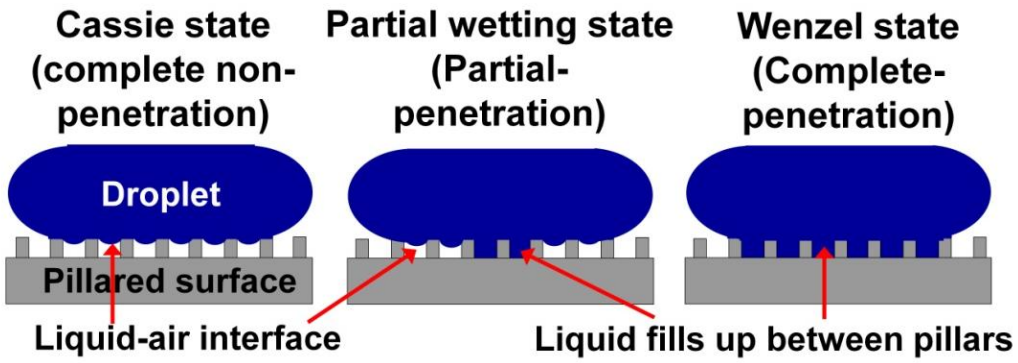
Patil, Sharma, Bhardwaj, Exp Therm. Flu. Sci., 2016

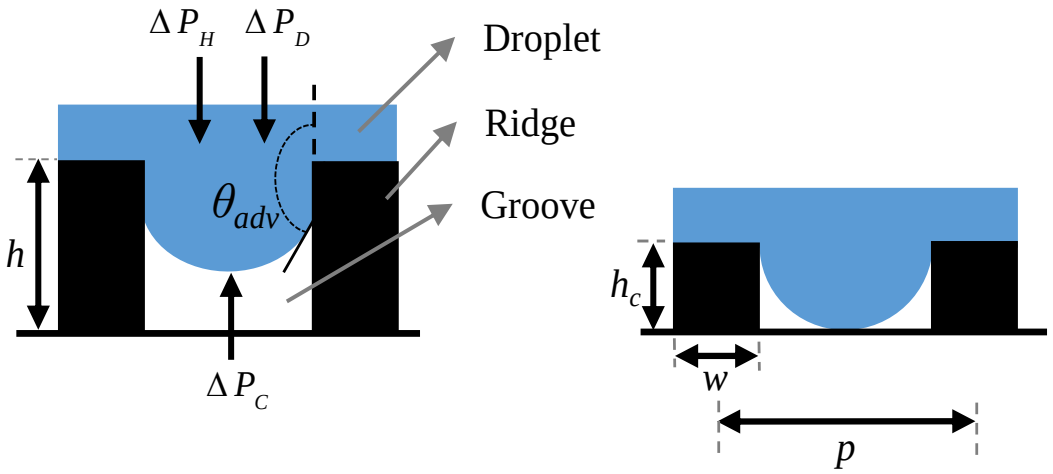
..and on microgrooved surfaces

Malla, Patil, Bhardwaj , Neild, Langmuir, 2017



Cassie to Wenzel Wetting Transition

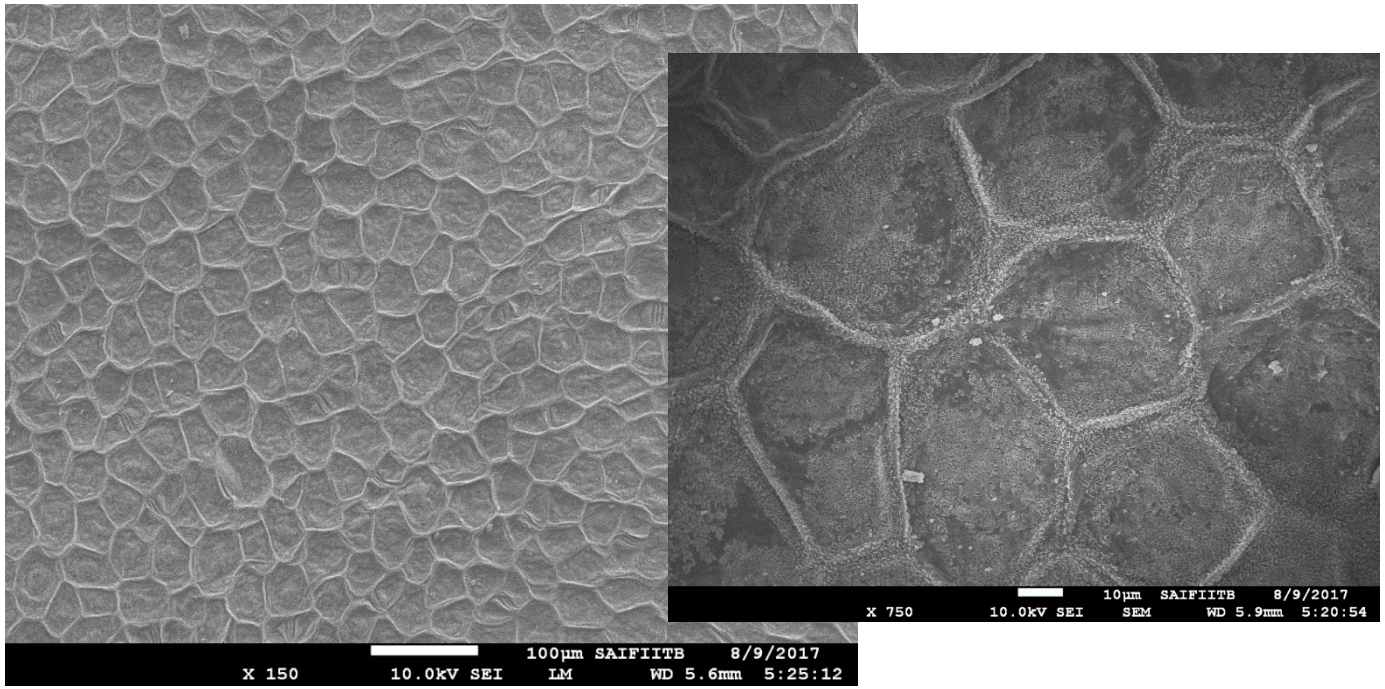


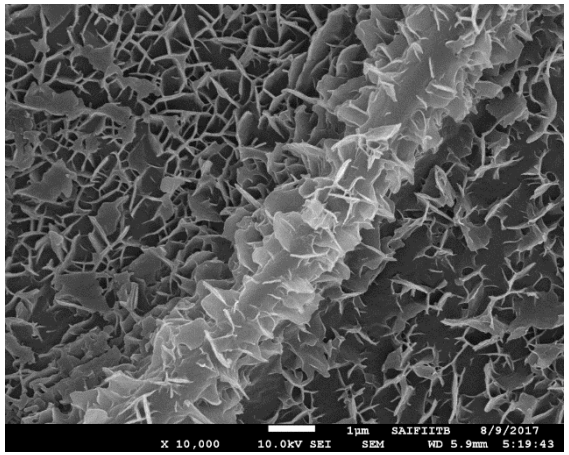


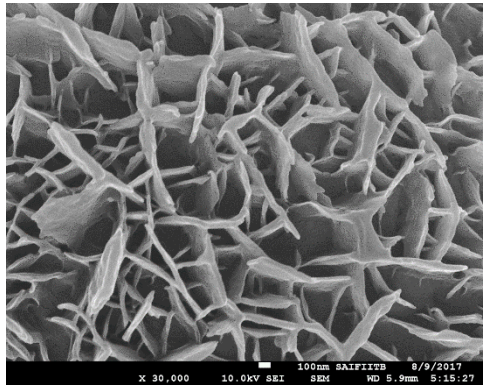
Depinning **Sagging**

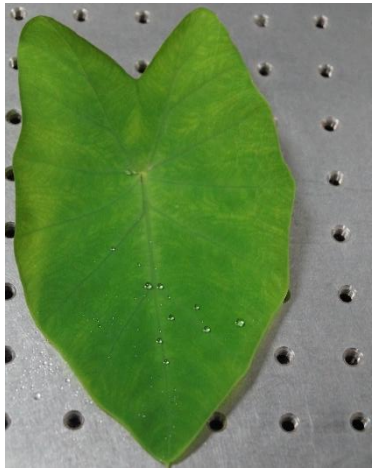
Malla, Patil, Bhardwaj , Neild, Langmuir, 2017

Wetting characterization of Elephant ear (*Colocasia)* leaf





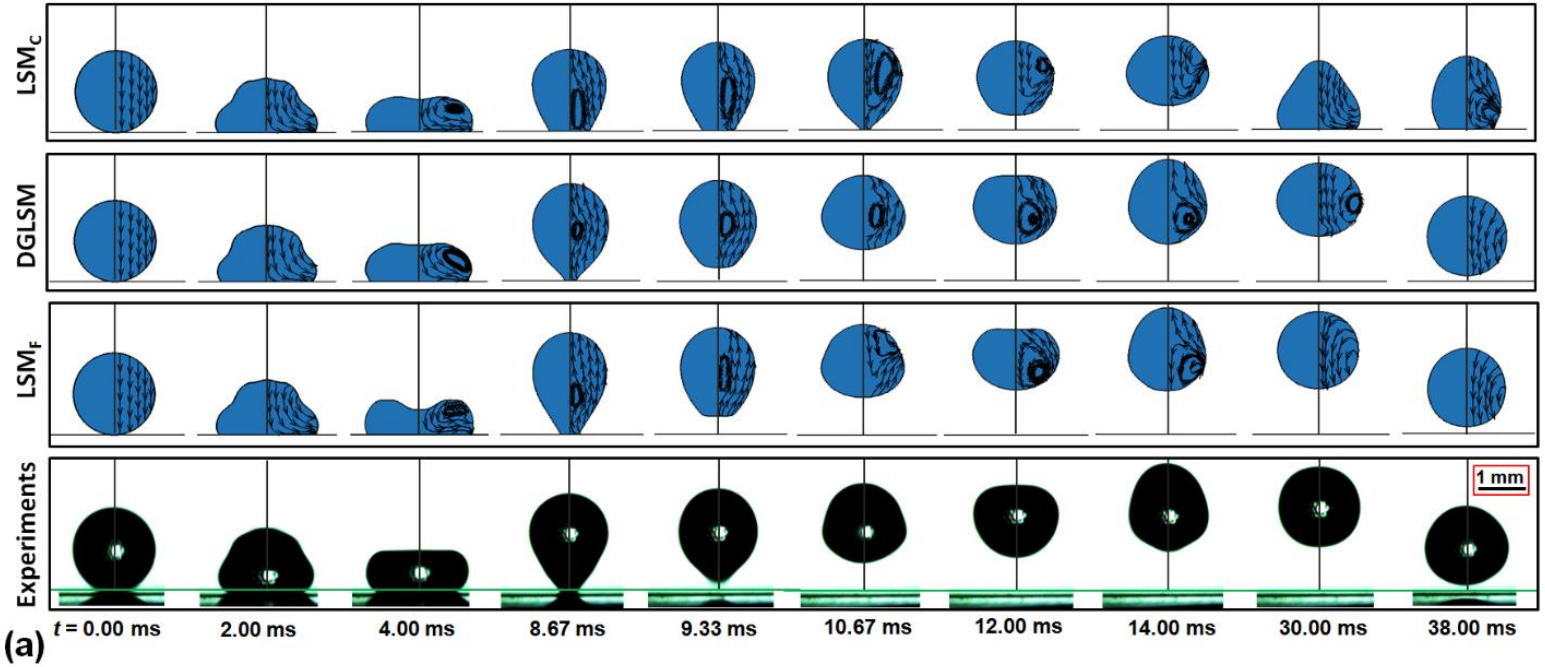


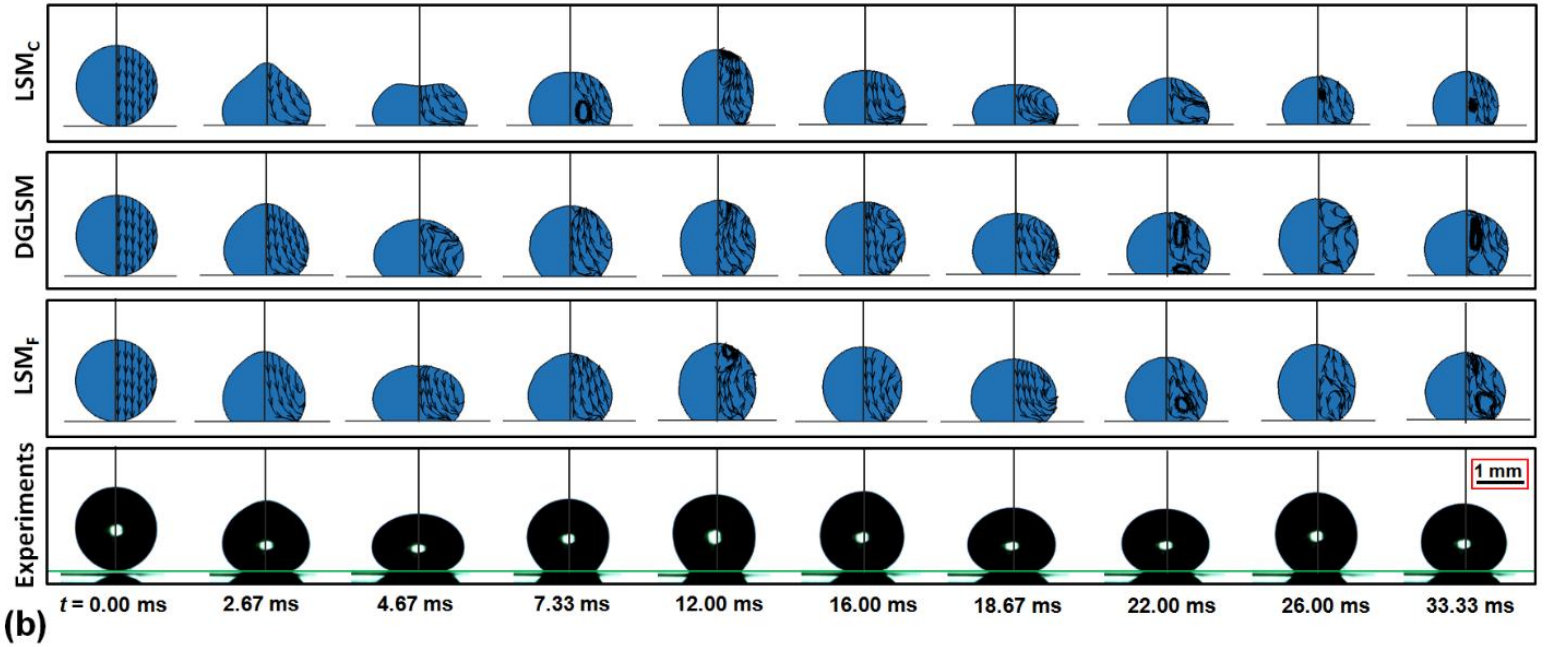


$\theta \sim 160^{o}$

Modeling vs. Measurements

Patil, Sharma, Bhardwaj , Int. J. Multiphase Flow, 2016



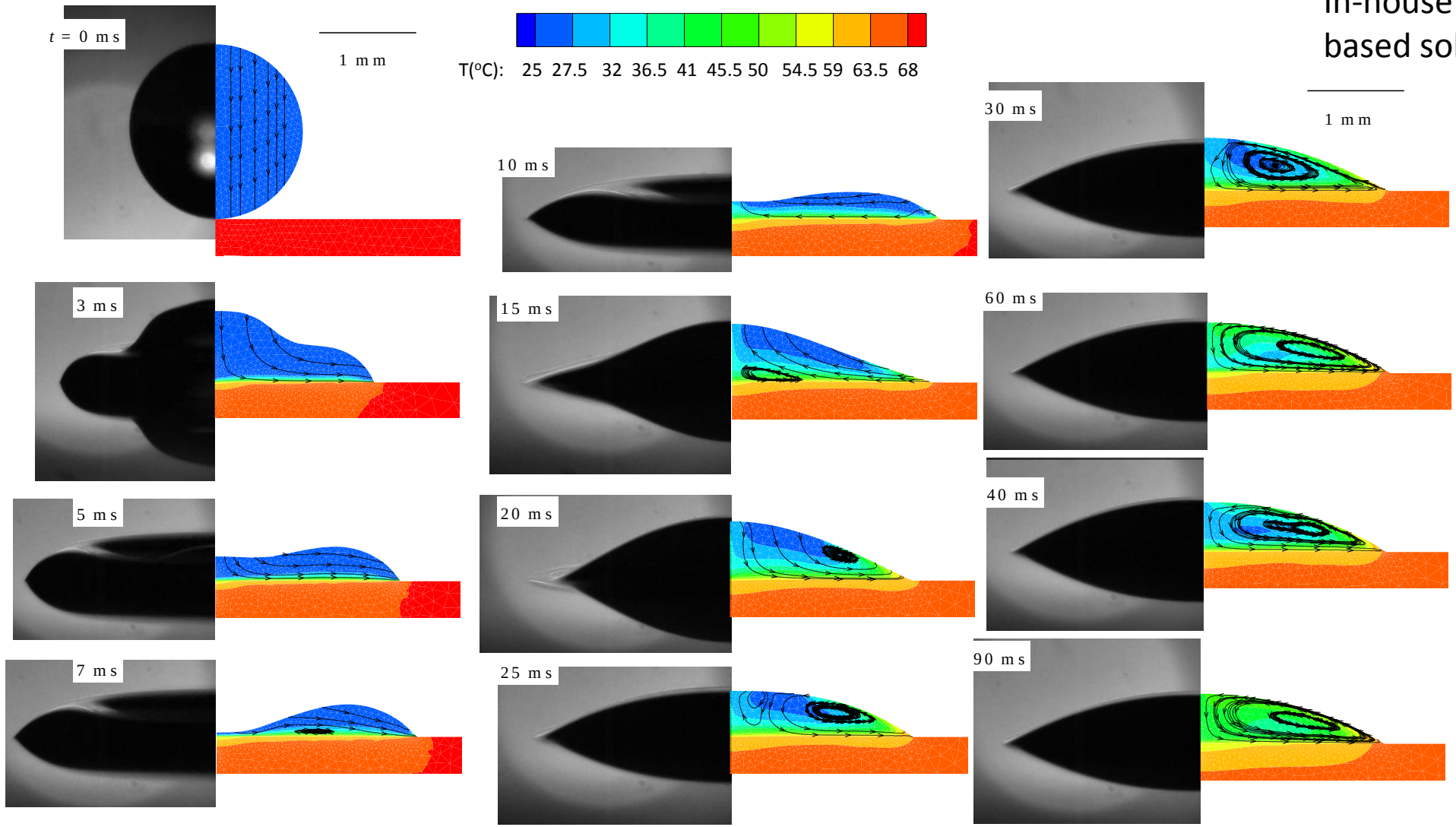


Level-set based solver developed in Prof. Sharma group

Non-isothermal impact of a pure liquid droplet

Parameters: Isopropanol drop on fused silica, d_0 = 1.8 mm, v_0 = 0.37 m/s,
Initial drop and substrate temperature = 25°C and 68 °C, respectively

In-house finite-element based solver



R. Bhardwaj, J P Longtin and D. Attinger, *Int J Heat and Mass transfer*, 2010.

Acknowledgements

- PhD students
- Collaborator: Prof. Atul Sharma
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- IITB Central facilities: CEN, CRNTS
- Department facility: Profilometer, Infrared camera
- IRCC Award Committee

Questions, Comments?

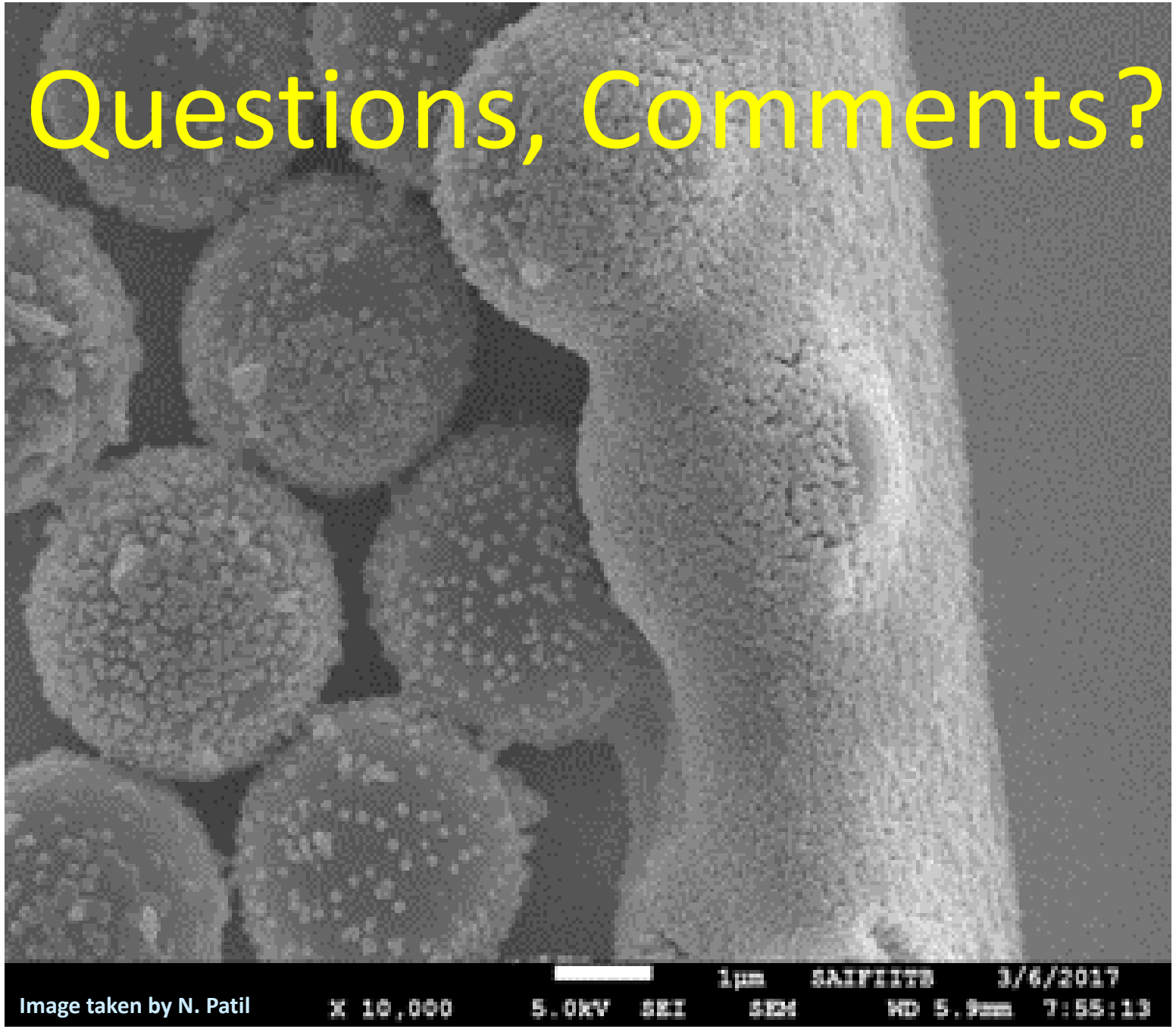

Image taken by N. Patil

Image taken by M. Kumar