



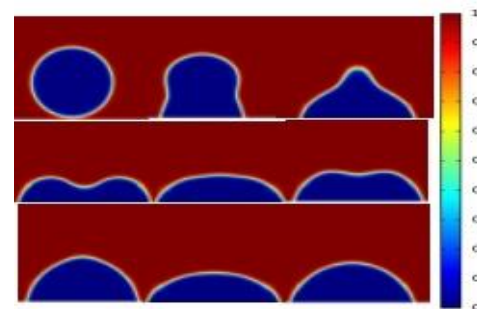
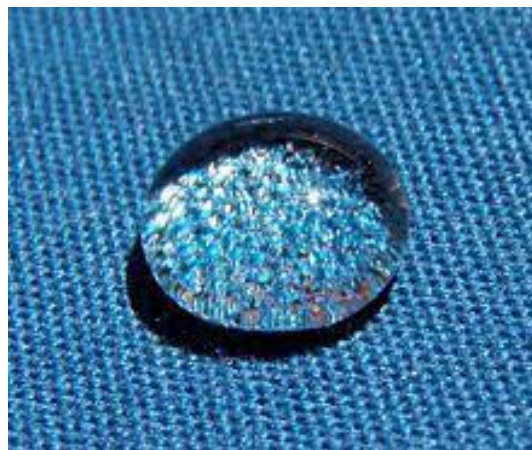
V International Conference on Ultrafast Optical Science  
«UltrafastLight-2021»

# How surface relief affects wettability and cell behavior on ultra-short laser-textured surfaces

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# Cells on surfaces

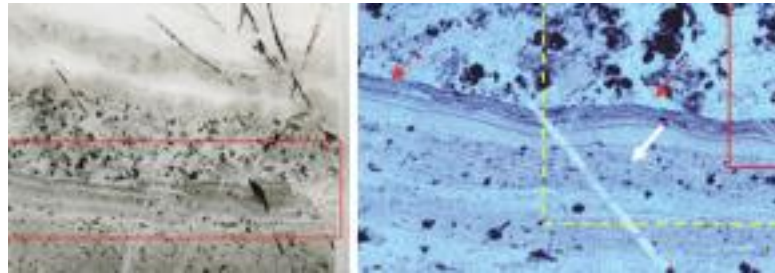
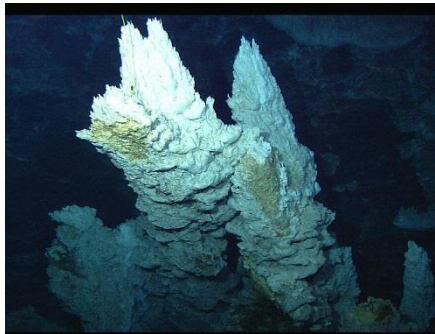
## On the origin of life: recent engineer's point of view



There are more and more new evidences that “first cells could have formed at **the surface of porous minerals**” ...

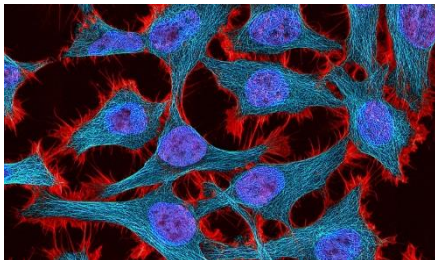
### HYDROTHERMAL-SEDIMENTARY ORIGIN OF LIFE

*Westall et al ASTROBIOLOGY V 18 (3) 2018*

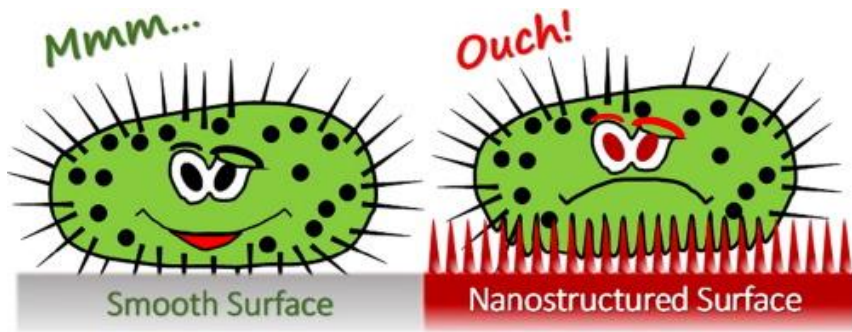


“A primeval metabolism begins in water **at the surface of minerals...**”

*These promote the polymerization of some of the elementary building blocks, including RNAs. An RNA-metabolism world develops and leads to the replication of these RNAs, eventually forming an RNA-genome world which then uses RNA molecules as information templates (primitive genes) rather than as direct substrates for metabolism.*



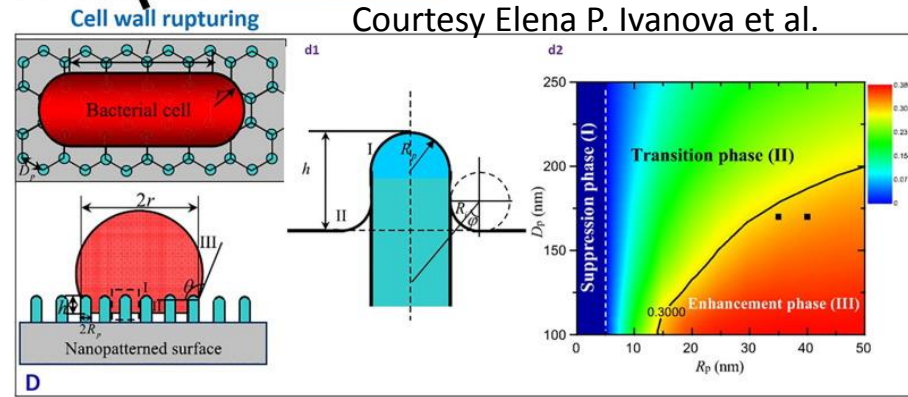
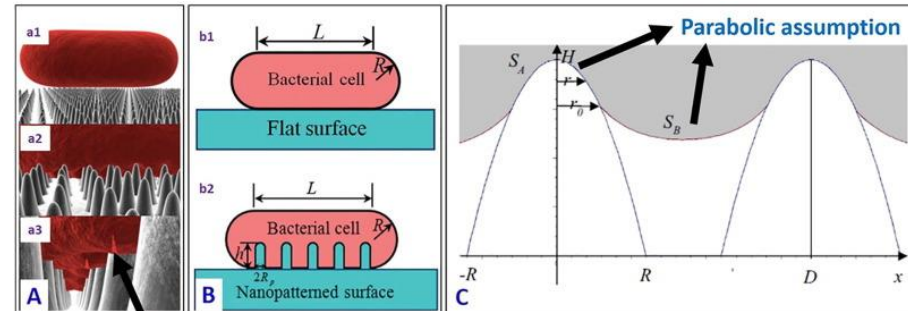
# Cells on surfaces



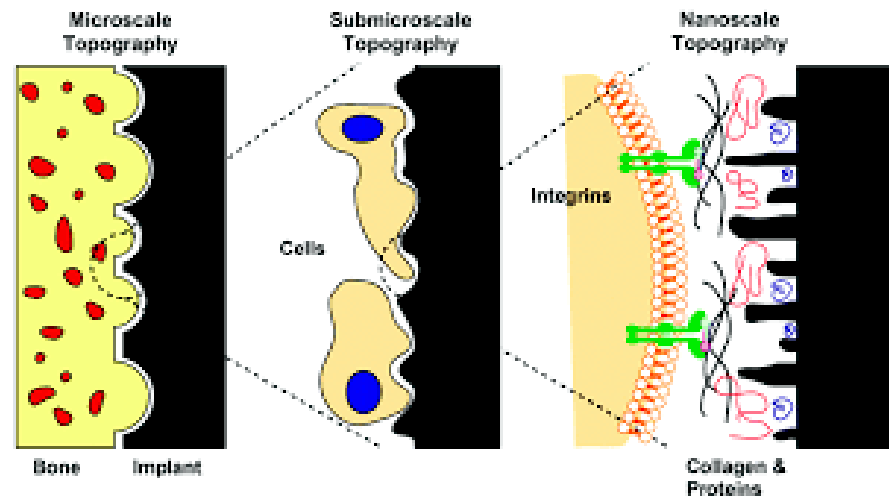
Between protection and defence ?

**Numerous factors can be important**

- cell types, size, properties
- surface material
- background gas or liquid
- surface topography
- topology
- Etc...

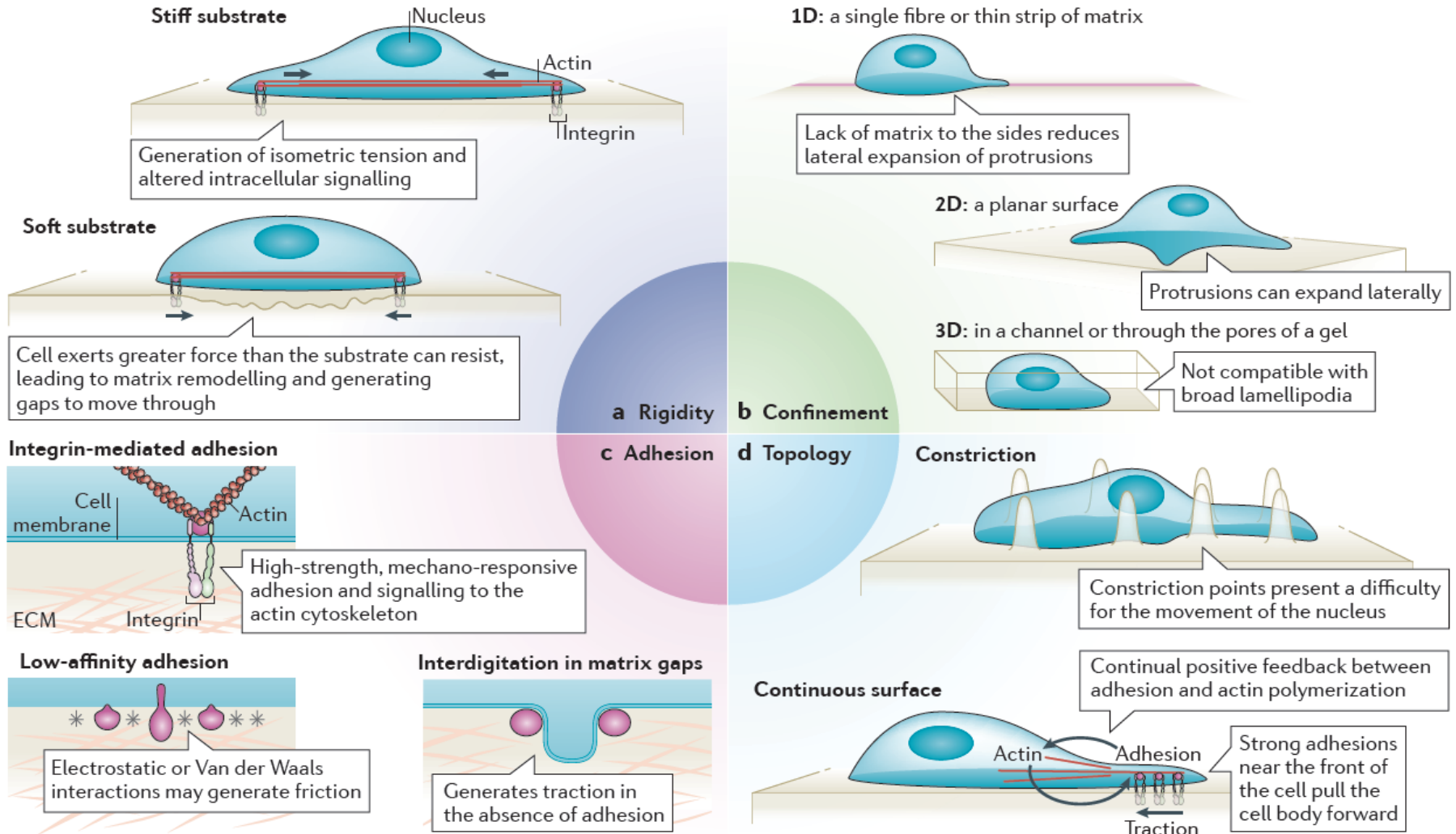


Courtesy Elena P. Ivanova et al.

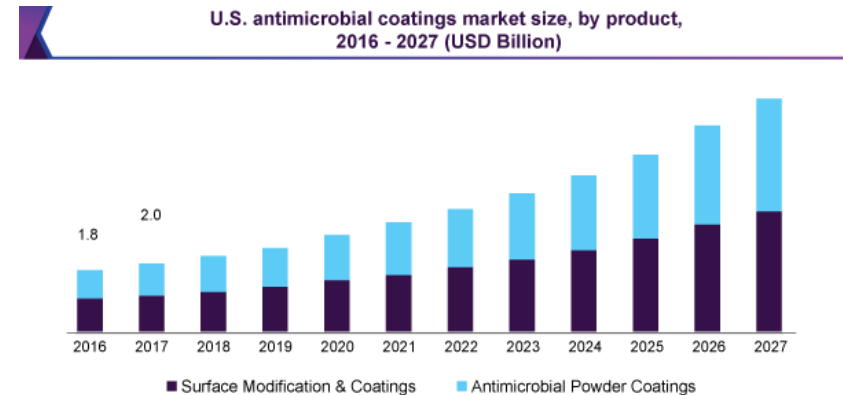
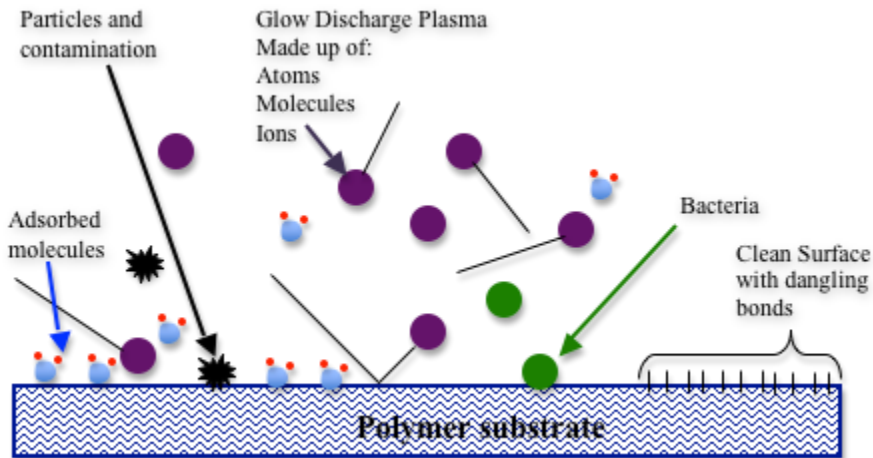




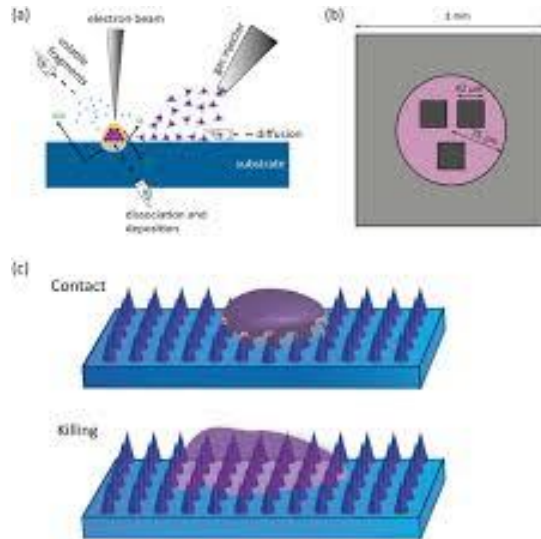
# Cells : physical influences



# Antimicrobial coatings vs surface texturing



## Bio-inspired surface structures



## Microbes include:

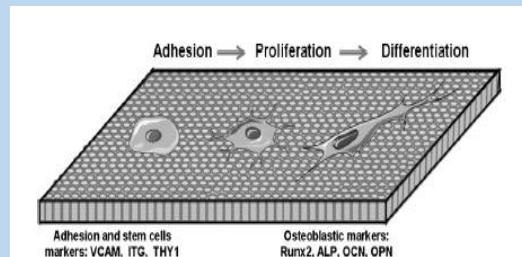
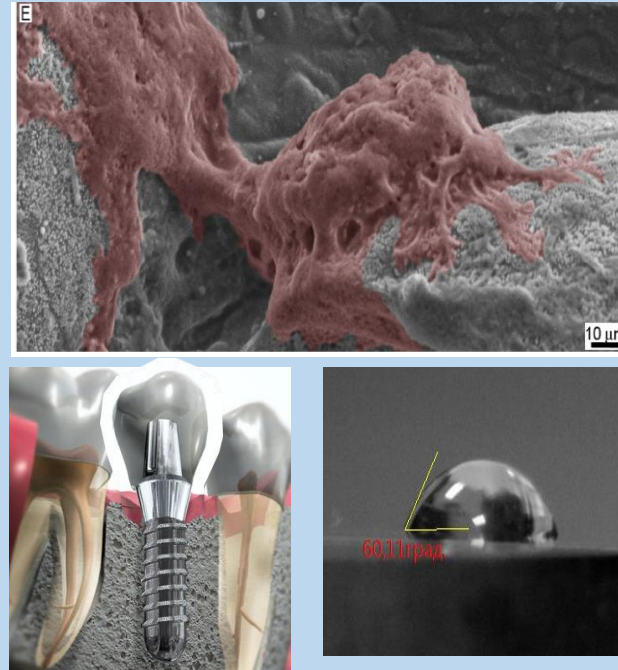
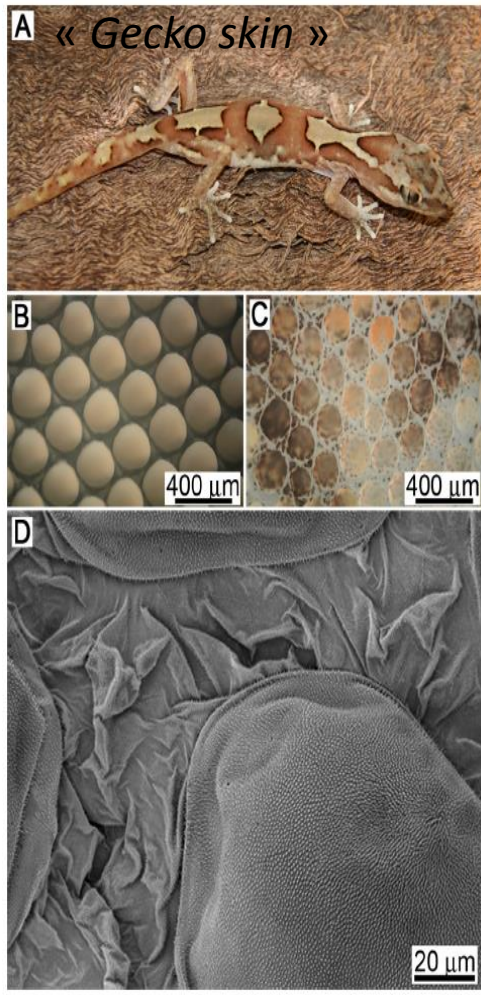
- fungi
- bacteria
- algae
- virus



**Nature Helps: Toward Bioinspired Bactericidal Nanopatterns**

Mahya Ganjian et al, Advanced Materials, 06 June 2019

# Role of textured surfaces



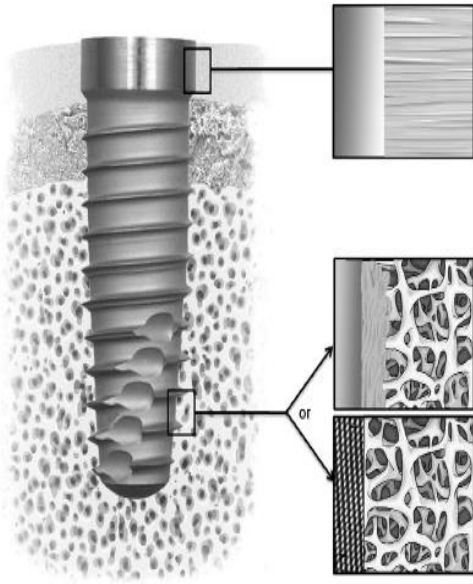
- Analogy with **the gecko skin** - wetting control and adhesion properties
- The texturing of surfaces is **a key step toward better bio-integration** of prostheses, implants, scaffolds
- **Hydrophilic** surface promotes the interaction of the surface with cellular elements, which is of particular importance in the **early stages of osseointegration**

G. S. Watson et al. « A gecko skin micro/nanostructure ... »  
*Acta Biomaterialia* 21 (2015), 109-122

S. Lavenus et al., *Impact of nanotechnology on dental implants.*

Yu. Karlagina et al.  
 ITMO Univ.

# Dental implants: different parts - different treatment

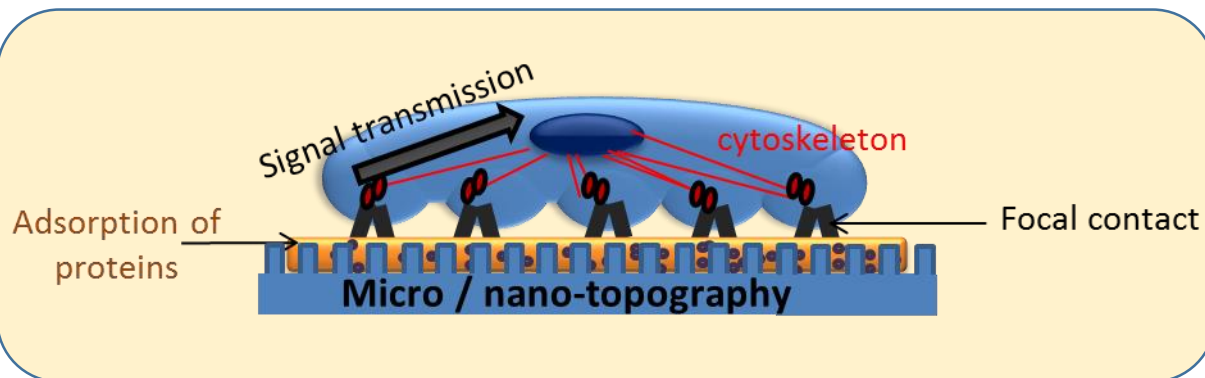


**In contact with the gingiva** – a texture allowing the development of gingival fibroblasts and limiting the adhesion of bacteria.

**In contact with the bone tissue** - should promote the differentiation and mineralization of bone cells to optimize osseointegration.

Here, we will concentrate on osseointegration

## Stem cells on textured surfaces

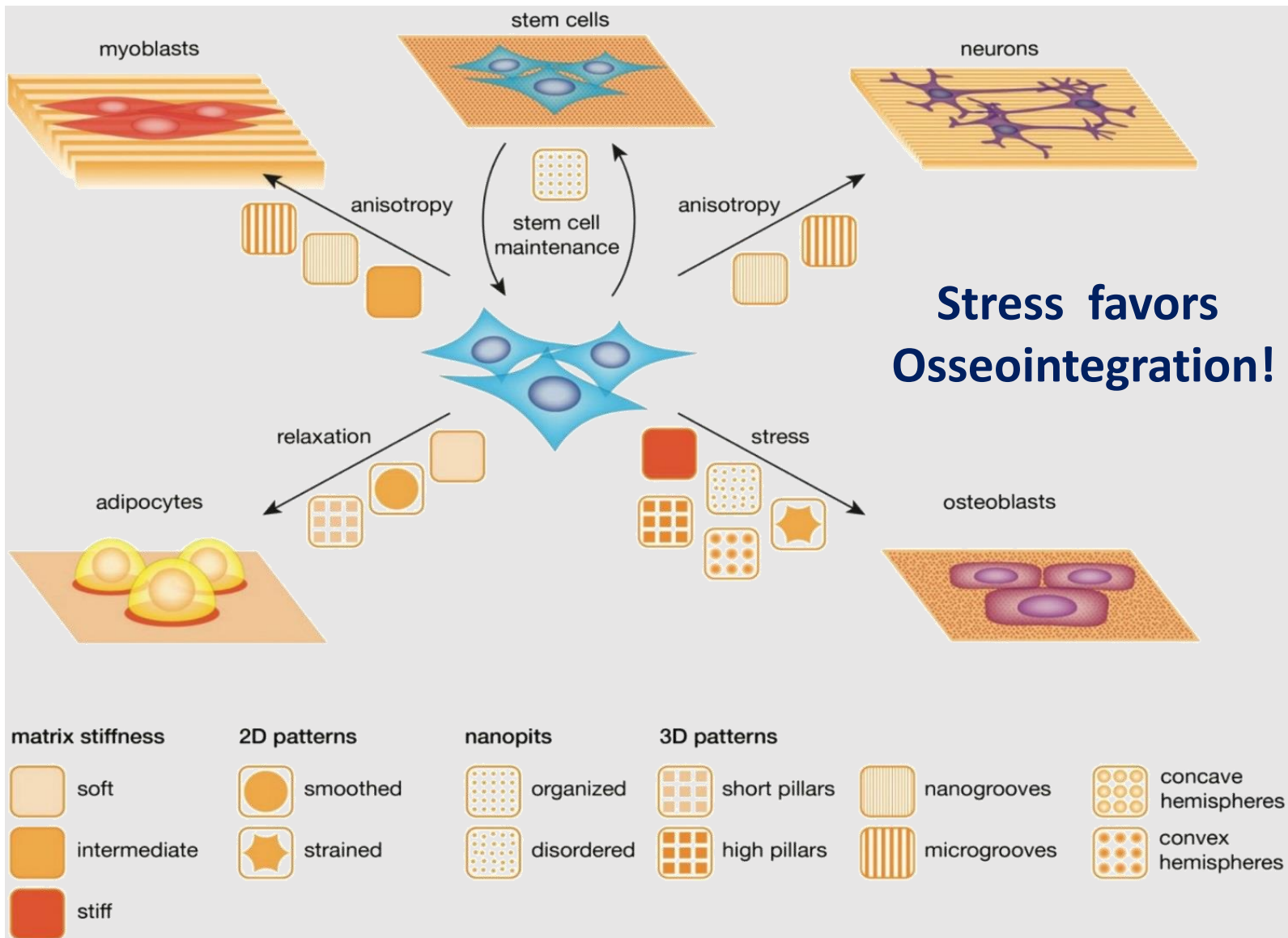


- Mechanotransduction
- Growth
- Osteoblast differentiation



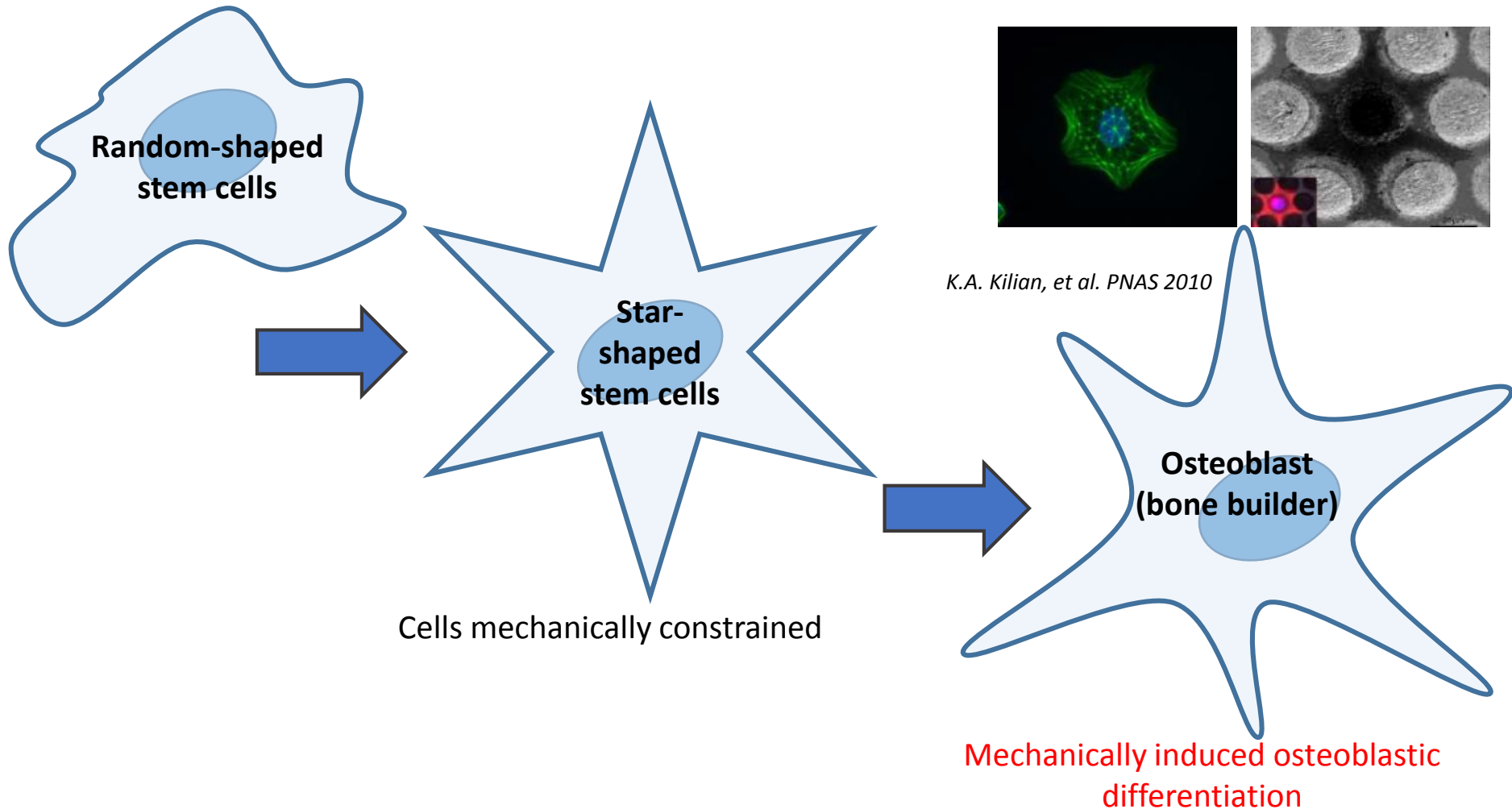
# Surface Modifications for Osteoblastic Differentiation

*K.A. Kilian et al., PNAS 2010*



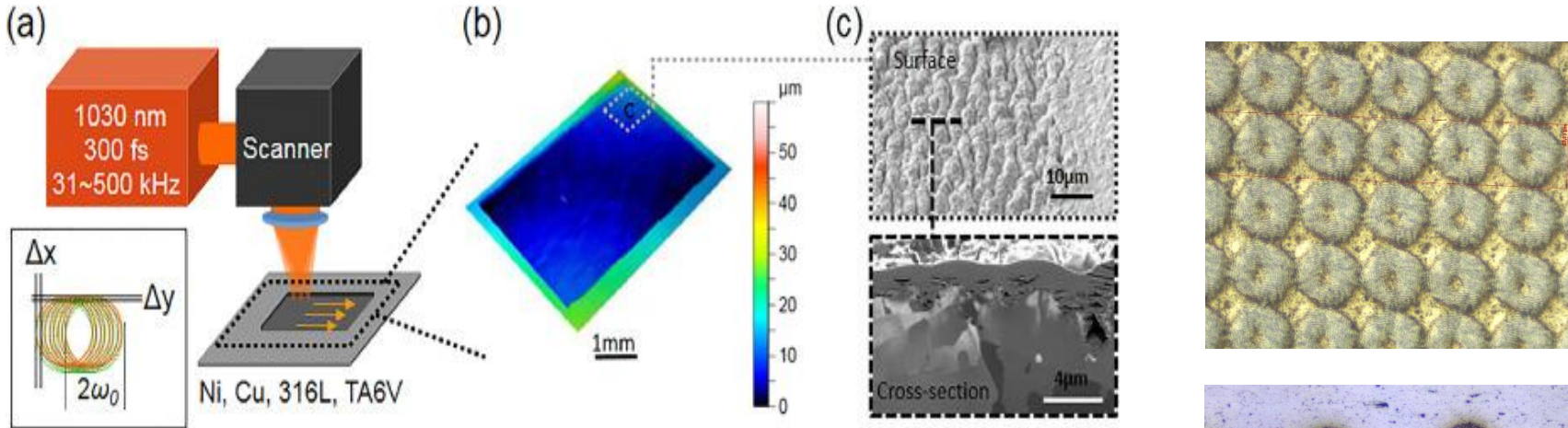


# Ways to get osteoblast differentiation

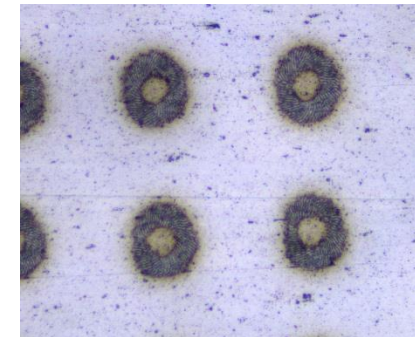
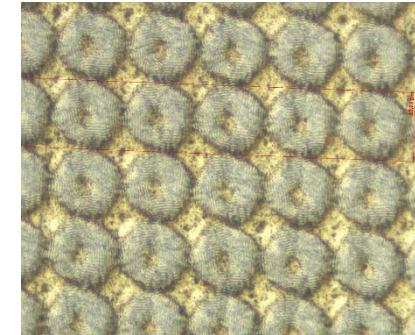
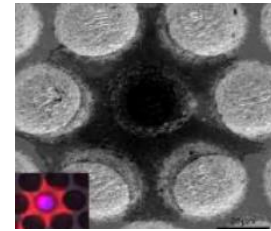


**We will try to guide cell to get a « star-like » extended shape to favor osseointegration.**

# Advantages of Femtosecond Lasers



- Can easily produce surface structures
- Can vary the size and the shape of the structures by reducing the thermal effect
- Favors a better control and a better quality
- Can minimize contamination and debris
- Can alternate hydrophobic and hydrophilic properties



**It remains to define the best surface relief, the optimum laser parameters.**

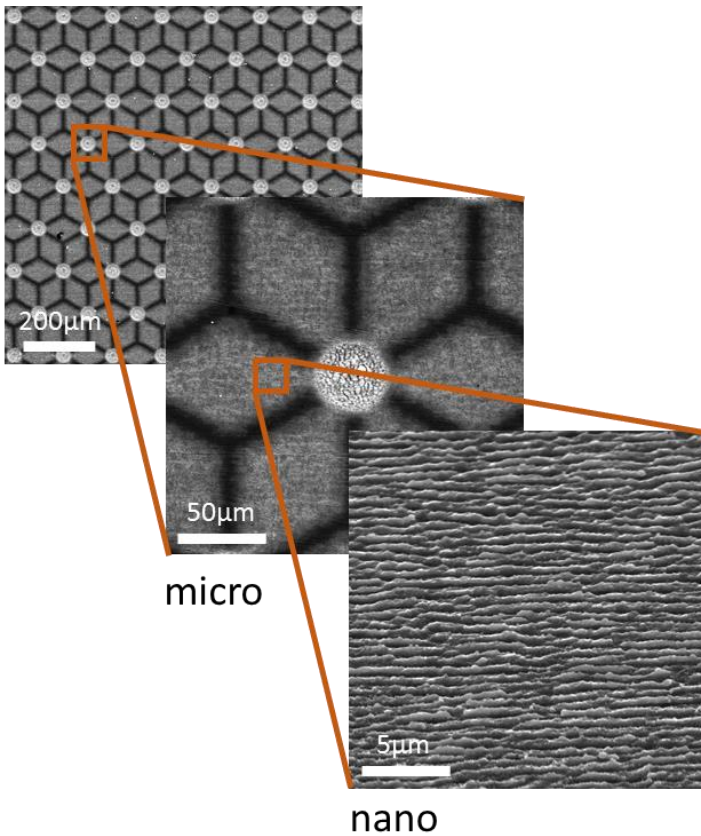
**For this, a better understanding of wetting on textured surfaces is required.**



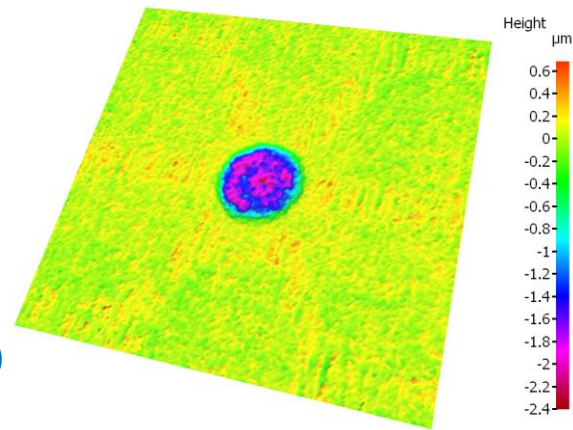
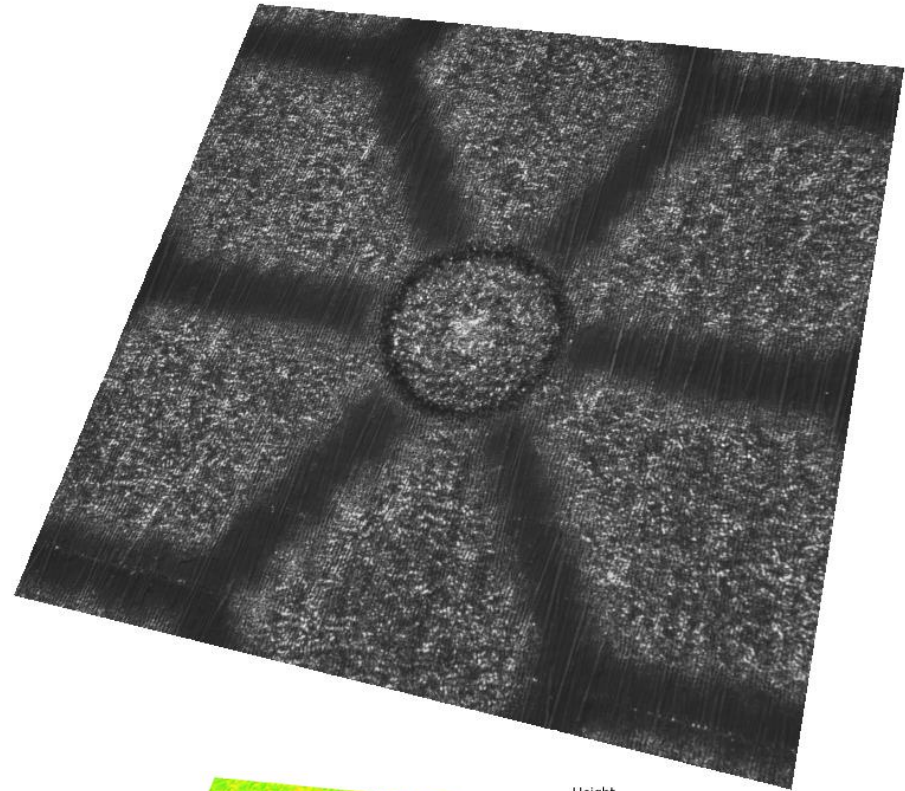
*X. Sedao et al. Optics and Lasers in Engineering*  
116, May 2019, Pages 68-74

# Multi-scale Laser Patterning

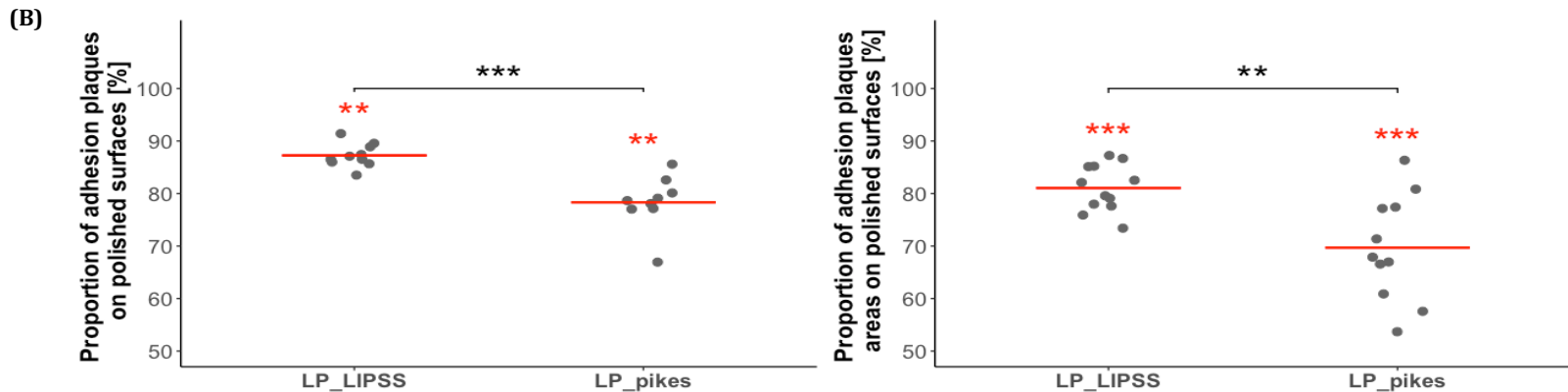
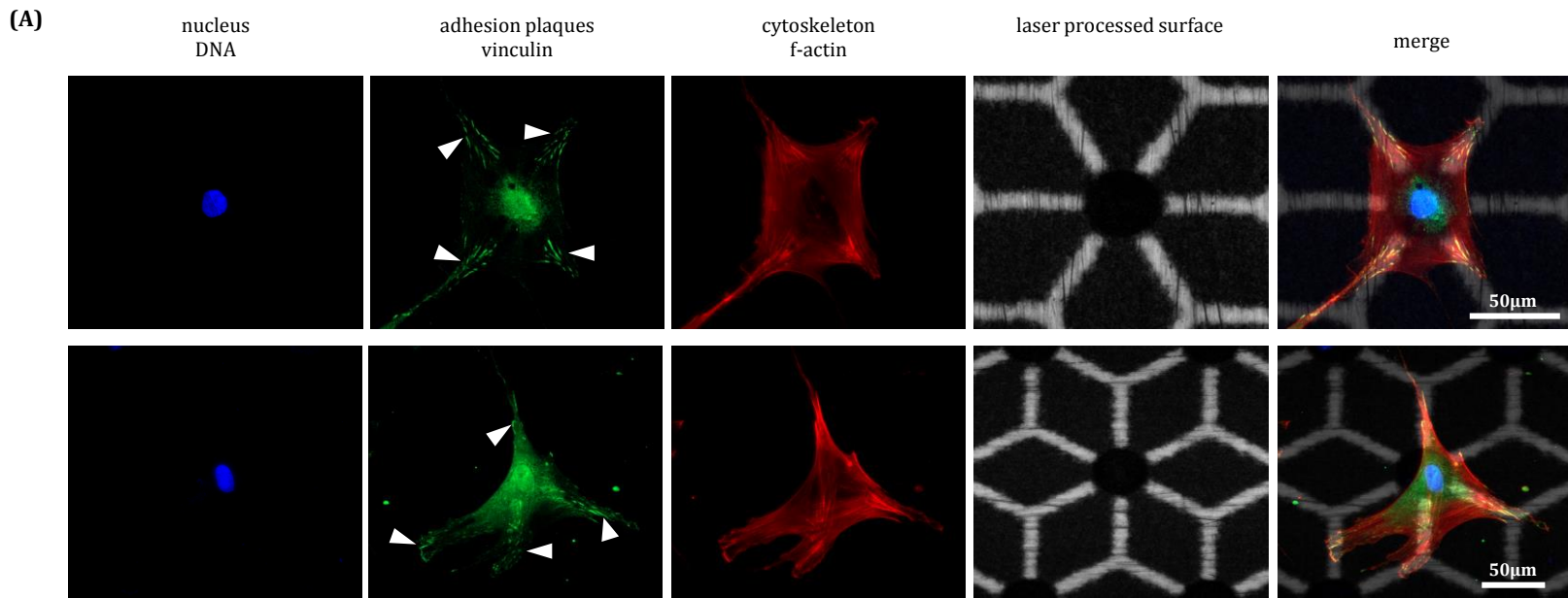
## Hierarchical surface relief



**Knowledge-Based**







(A) hMSCs exhibits preferential focal adhesion location on polished areas (white arrows), nucleus inside a pit, and cytoskeleton star-like shaped. DNA is shown in blue, vinculin in green, actin in red.

(B) Ratio of **adhesion plaques on polished regions** compared to **adhesion plaques on laser-nanostructured** ones was obtained either by counting the number of adhesion plaques per cell (left panel) or by measuring the areas of the adhesion plaques per cell (right panel). **Data shows a significant differences between LP\_LIPSS and LP\_spikes concerning the number and the area of adhesion plaques per cell. Red lines denote mean values.**

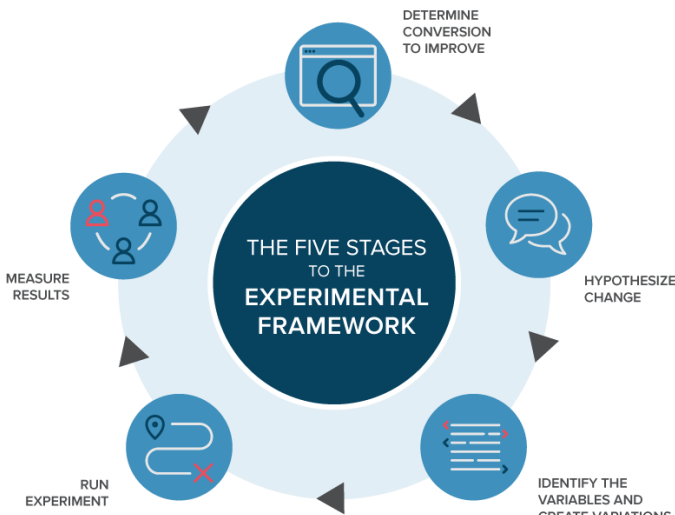
# How Modeling Can Help?



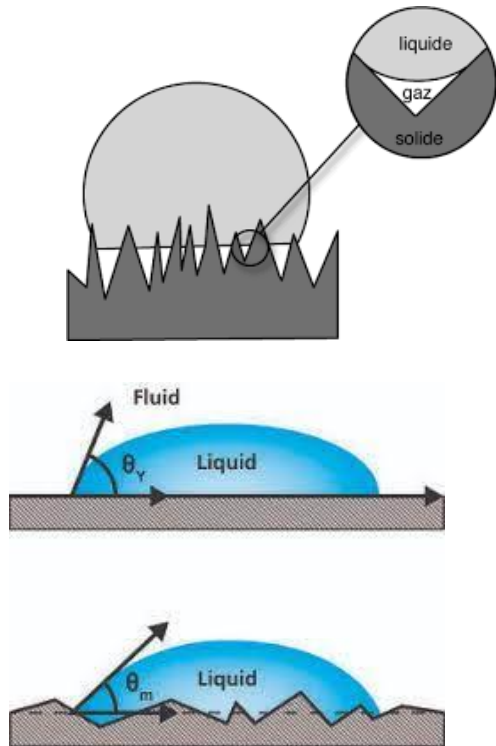
## Main objectives of the modeling

- to reduce the number of tests
- to optimize laser treatment

- To explain/predict the connections of cell/bacteria behavior with surface materials and relief
- To explain/predict the best materials and structure parameters for the required wettability
- To determine the best/required laser parameters

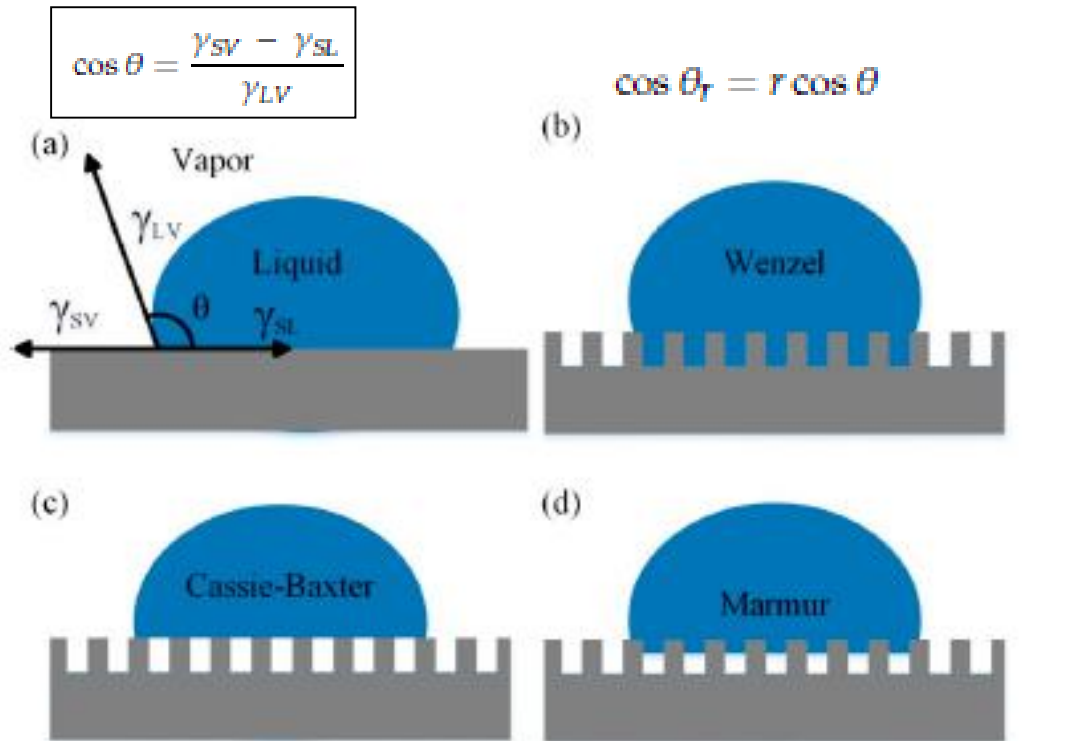


# Effects of surfaces roughness on wettability



Wettability changes with surface relief, with surface/liquid/gas compositions, with droplet size and...

**Wettability changes with ...time!**



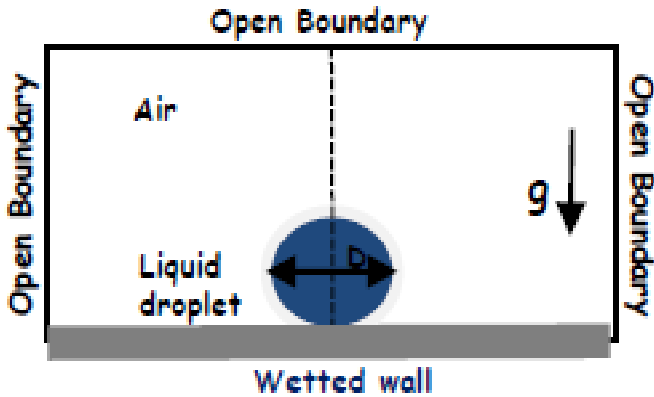
$$\cos \theta_r = f_{SL} \cos \theta_1 + f_{LA} \cos \theta_2$$

$$\cos \theta_r = r f_{SL} \cos \theta + f_{SL} - 1$$

The theories of wetting for a textured surface are often based on Cassi-Baxter and Wenzel models that are over 50 years old and are oversimplified.



# Computational Fluid-Dynamics CFD Model



## Level Set Method (Interface tracking)

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = \gamma \nabla \cdot (\epsilon_{ls} \nabla \phi - \phi(1 - \phi) \frac{\nabla \phi}{|\nabla \phi|})$$

$$\rho = \rho_1 + (\rho_2 - \rho_1)\phi$$

$$\mu = \mu_1 + (\mu_2 - \mu_1)\phi$$

## Kisler Model: Dynamic contact angle ( $\theta_d$ )

$$\theta_d = f_H [Ca + f_H^{-1}(\theta_e)]$$

$$f_H = \arccos \left\{ 1 - 2 \tanh \left[ 5.16 \left( \frac{x}{1 + 1.31x^{0.99}} \right)^{0.706} \right] \right\}$$

## Navier-Stokes (Fluid Flow)

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho (\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \cdot [-P\mathbf{I} + \mathbf{K}] + \mathbf{F} + \rho \mathbf{g}$$

$$\rho \nabla \cdot \mathbf{u} = 0$$

$$\mathbf{K} = \mu (\nabla \mathbf{u} + (\nabla \mathbf{u})^T)$$

$$F_{st} = \sigma \delta \kappa n_{int} + \delta \nabla_s \sigma$$

$Ca = \frac{\mu U_{cl}}{\sigma}$  is Capillary number representing the relative effect of viscous drag forces versus surface tension forces acting across interface

$U_{cl}$  is contact-line velocity

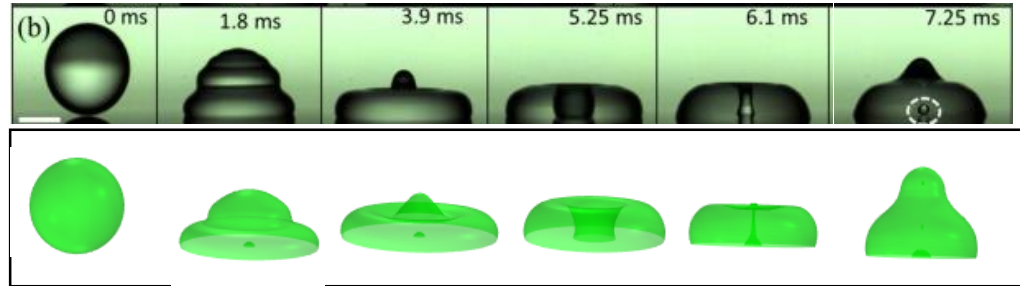
S.F Kisler, Hydrodynamics of wetting, JC Berg (Ed.) Wettability, New York, 1993.

# Calculation Results: Model Validation

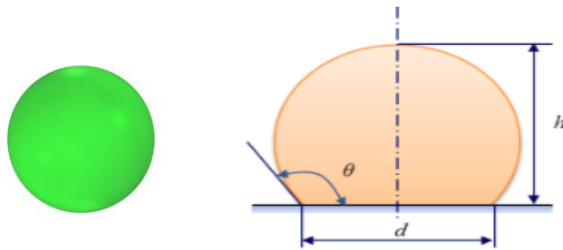
## Simulation of water droplet falling on glass

### Properties of Water and Air

Parameters	Value
Density of water	997 Kg/m <sup>3</sup>
Dyn. visc. of water	0.9 mPa.s
Density of air	1.204 Kg/m <sup>3</sup>
Dyn. visc. of air	1.814*10e-5
Surf. liq.-air	0.0718



Shiji et al (2018)

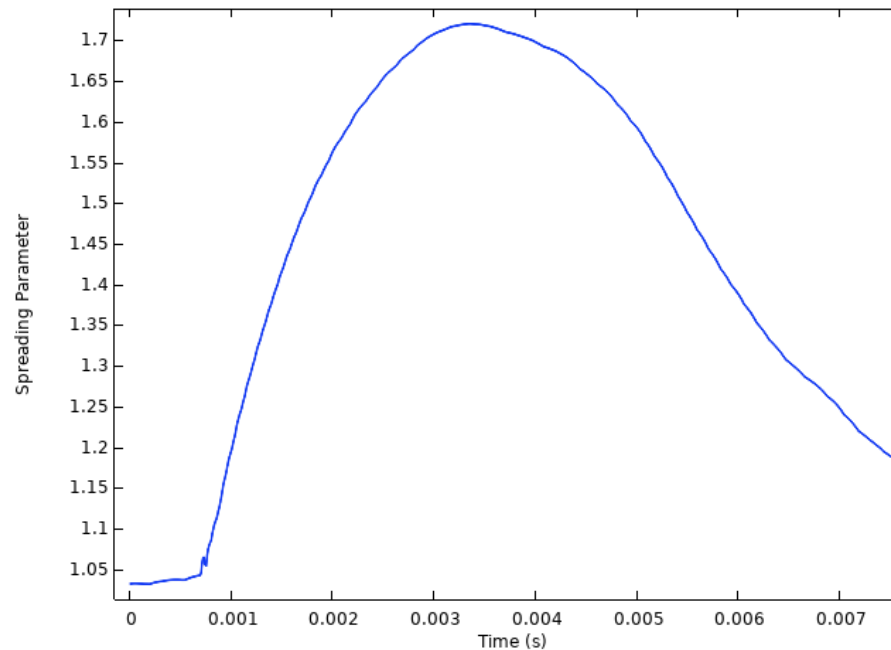


Diameter of droplet = 2 mm

Impact velocity = 0.56 m/s

Equili. Contact Angle = 106

### Spreading Parameter ( $d_s/d_0$ )

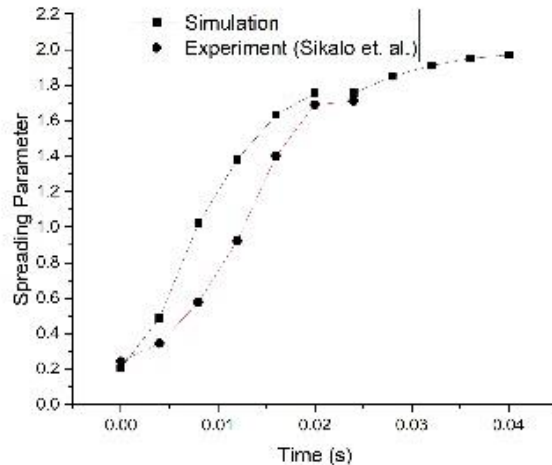


Shiji et al (2018), Impact of viscous on different wettability, Journal Colloid & Interface Science (Experiment)

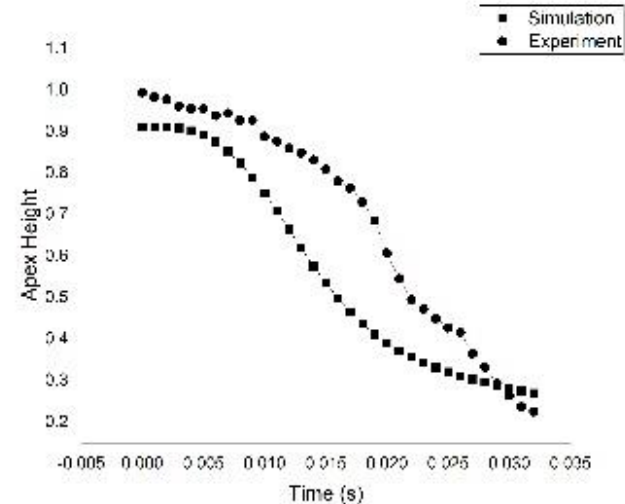
# CFD Results: Droplet Dynamics

## Glycerol Droplet Dynamics on wax: Experiment vs Simulation

$ds/dt$

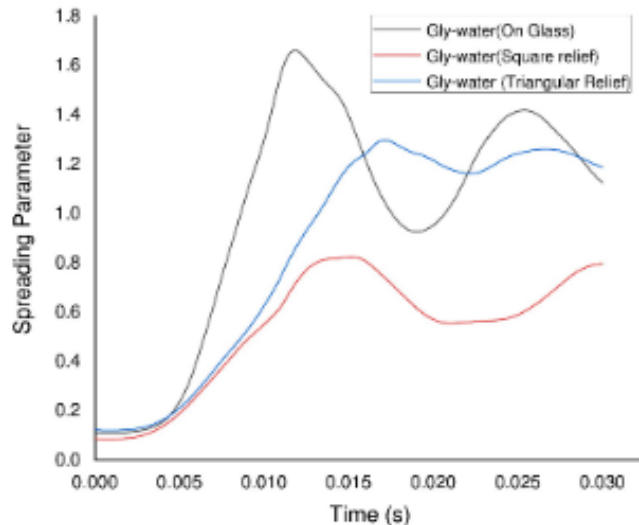


$dh/dt$



## Glycerol-Water Droplet dynamics on different textured surfaces

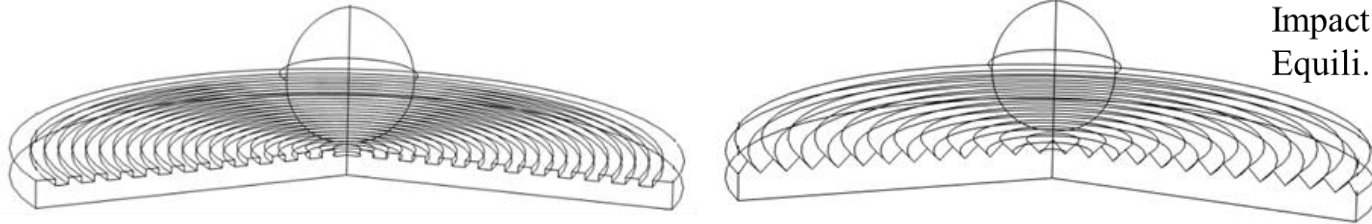
$ds/dt$



- Simulation results obtained for 2.45mm glycerin droplet on wax at a contact of  $15^\circ$  is compared with the experiments.
- The initial spreading process for the droplet is due to the impact pressure and inertia.
- The dynamics of the droplet on the textured surfaces is different. There is a great impingement of the liquid upon impact. This effect is due to the air pressure within the relief and the roughness of the surface. Oscillations are then observed.

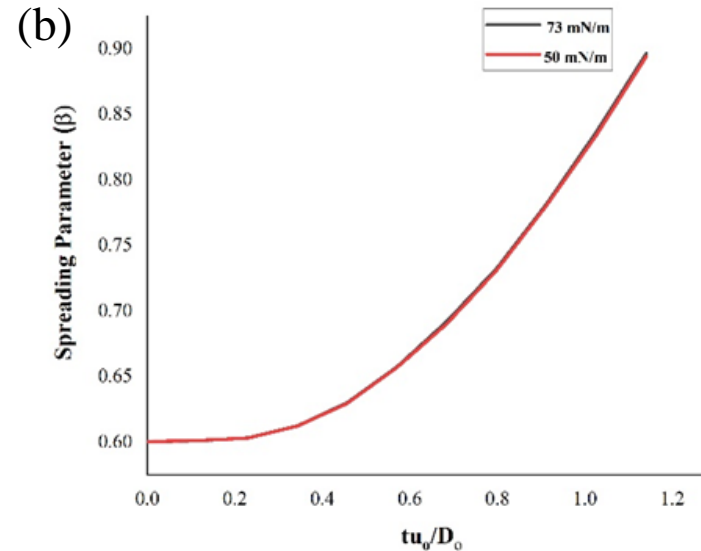
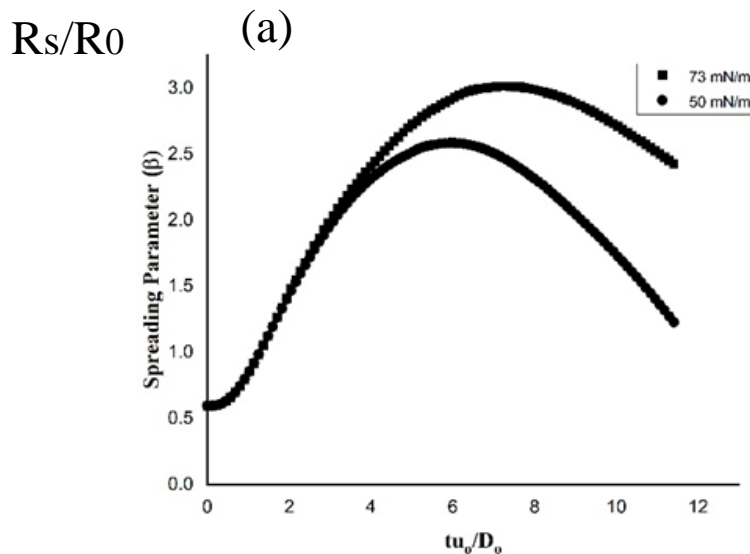


# CFD Results: Effects of surface tension on plain and textured surfaces



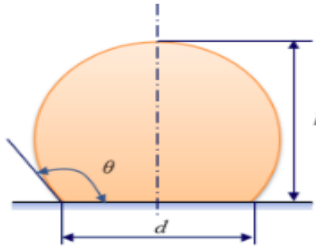
Diameter of droplet = 2 mm  
Impact velocity = 0.56 m/s  
Equili. Contact Angle = 106

Liquid droplet falls on the periodic rectangular and triangular relief



Spreading parameter on a plain (a) and on a triangular (b) Ti-6Al-4V surfaces at different surface tension.

# CFD results: role of the textured surface



$$\text{Spreading factor} = \frac{d}{D_0}$$

$$\text{Apex height} = \frac{h}{D_0}$$

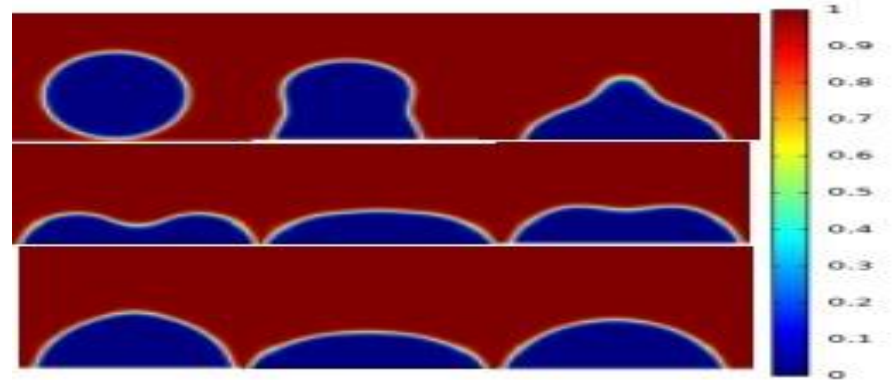
$d$  = diameter of droplet

$D_0$  = initial diameter

$h$  = apex height of droplet

diameter is 2mm  
 the static contact angle ( $\theta_e$ ) is  $76^\circ$   
 at impact velocity of 0.8 m/s

## Glycerol-water droplet on glass

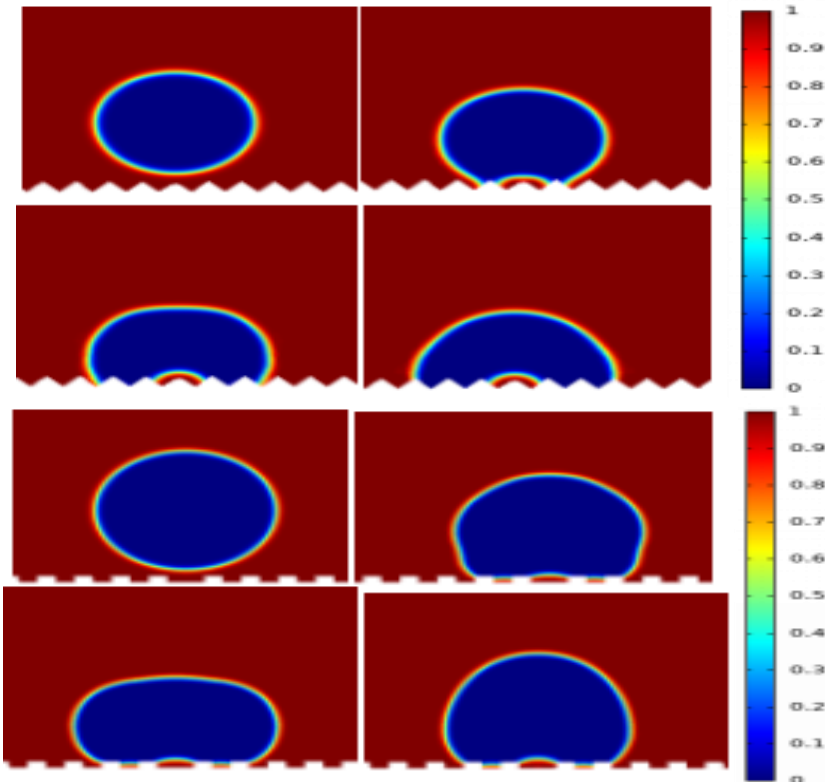


## Glycerol-water droplet on triangular relief surface

## Glycerol-water droplet on square relief surface

Parameters from:

Shiji L. et. al., Impact of viscous droplets on different wettable surfaces..., Journal of Colloid and Interface Science 516, 15 (2018), pp. 86-97.



## Summary

- **Femtosecond lasers** allow us the formation of complex surface reliefs.
- A connection between cell behavior and surface wettability has been established.
- Advanced laser processing solutions are promising for implants surface functionalization.
- **Surface relief, droplet size and impact velocity** play a role in wettability.
- **Spreading parameters such inertial, viscous, capillary and contact-line forces** strongly affect the dynamic contact angle and wetting.

**THANK YOU VERY MUCH FOR  
YOUR KIND ATTENTION!**