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Mathematical model of dropwise condensation on textured surfaces

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Introduction

- ▶ General issue: formation of water droplets in foggy days on interior side of car light shields.
- ▶ Idea for solving the problem: applying different texturing patterns on the vitreous substrate to control the rate of droplets growth.

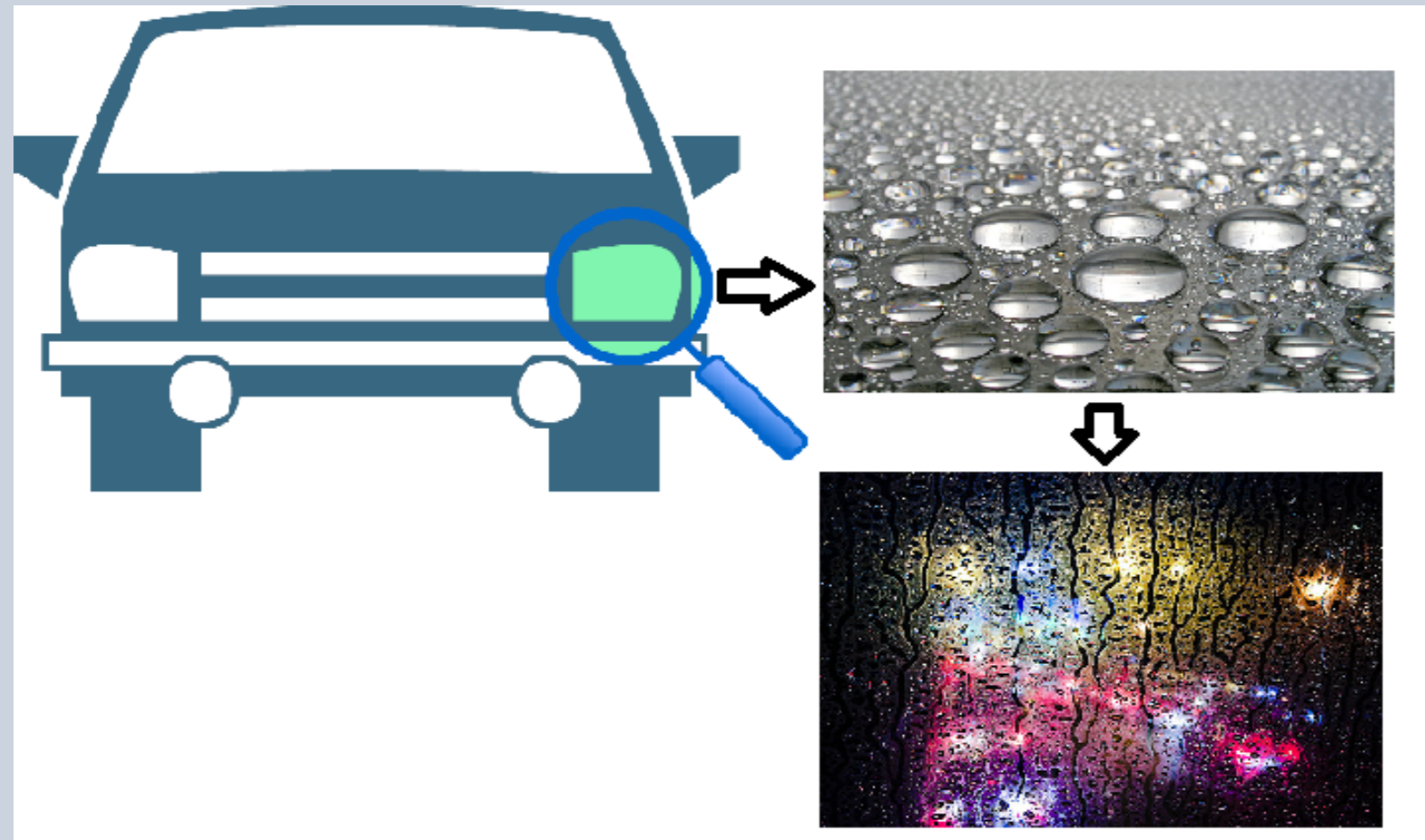


Figure: Formation of water droplets (because of dropwise condensation) on car light shields reduces light reflection in foggy days.

Dropwise condensation

The process of dropwise condensation consists of five main steps:

- ▶ nucleation of initial droplets
- ▶ growth rate due to adsorption
- ▶ growth rate due to coalescence
- ▶ nucleation of new small droplets
- ▶ sliding very big droplets from the surface.

Flat v.s textured substrates

The most important difference between droplets on flat and textured substrates: their geometry:

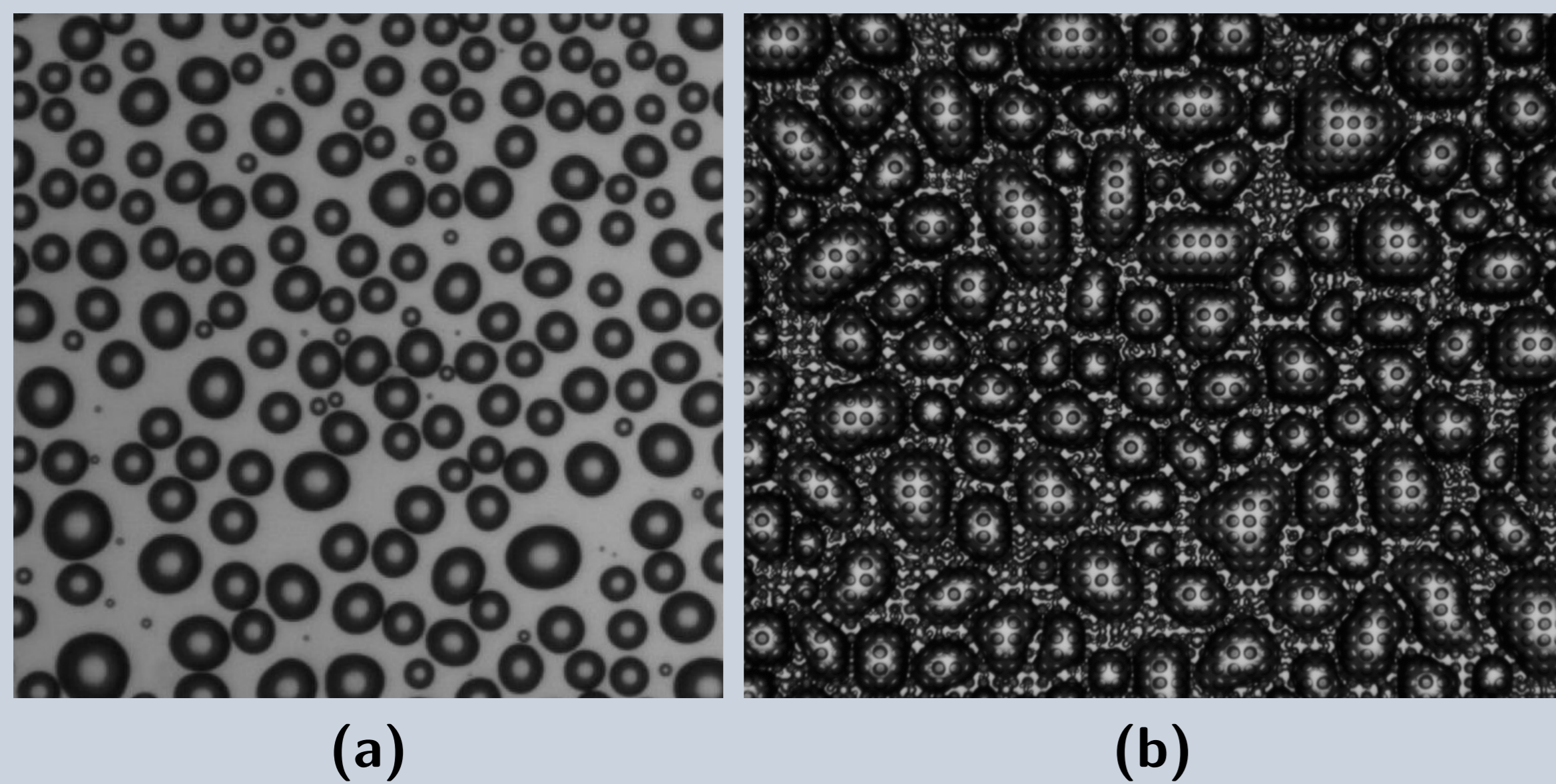


Figure: (a) Spherical droplets on the flat, (b) elliptical droplets on the sinusoidal substrates.

$$\text{Equation of sphere: } \frac{1}{r^2}(X - X_0)^2 + \frac{1}{r^2}(Y - Y_0)^2 + \frac{1}{r^2}(Z - Z_0)^2 = 1$$

$$\text{Equation of ellipsoid: } \frac{1}{a^2}(X - X_0)^2 + \frac{1}{b^2}(Y - Y_0)^2 + \frac{1}{c^2}(Z - Z_0)^2 = 1$$

Mathematical modeling

Aim: improving the existing models regarding circular droplets ([1]) for elliptical ones.
Adsorption of ellipsoidal droplets:

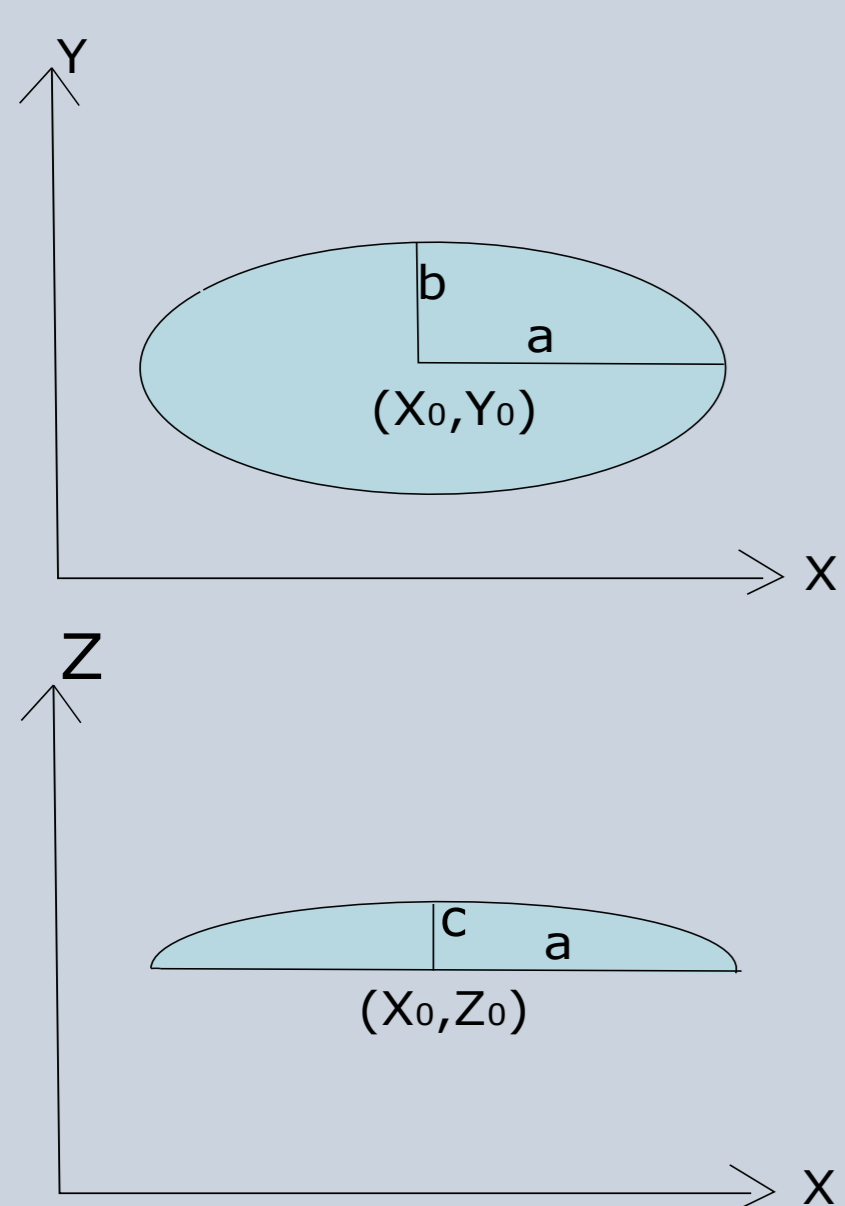


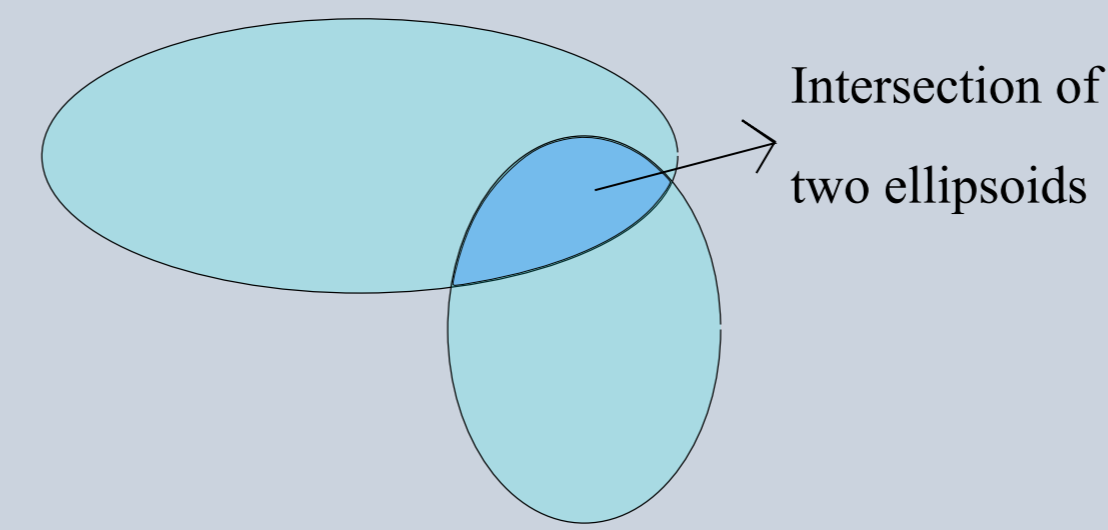
Figure: Ellipsoid in two planes $X - Y$ and $X - Z$.

$$a_k = a_{k-1} + \frac{da}{dt}, \quad (1)$$

where k represents the time step. For b and c the same equation can be written. $\frac{da}{dt}$ is the growth rate and can be calculated from adsorption laws.

Mathematical modeling

Coalescence of ellipsoidal droplets:



Intersection between two ellipses: solving the system of equations of two ellipses:

$$\begin{cases} A_1 X^2 + Y^2 = R_1, & (2) \\ A_2 (X - X_0)^2 + (Y - Y_0)^2 = R_2, & (3) \end{cases}$$

where $A_1 = \frac{b_1^2}{a_1^2}$ and $R_1 = b_1^2$, $A_2 = \frac{b_2^2}{a_2^2}$, and $R_2 = b_2^2$.

Figure: Checking for coalescence is done by verifying the existence of real intersection between two ellipses

Results

Model was applied on 6 pillared substrate:

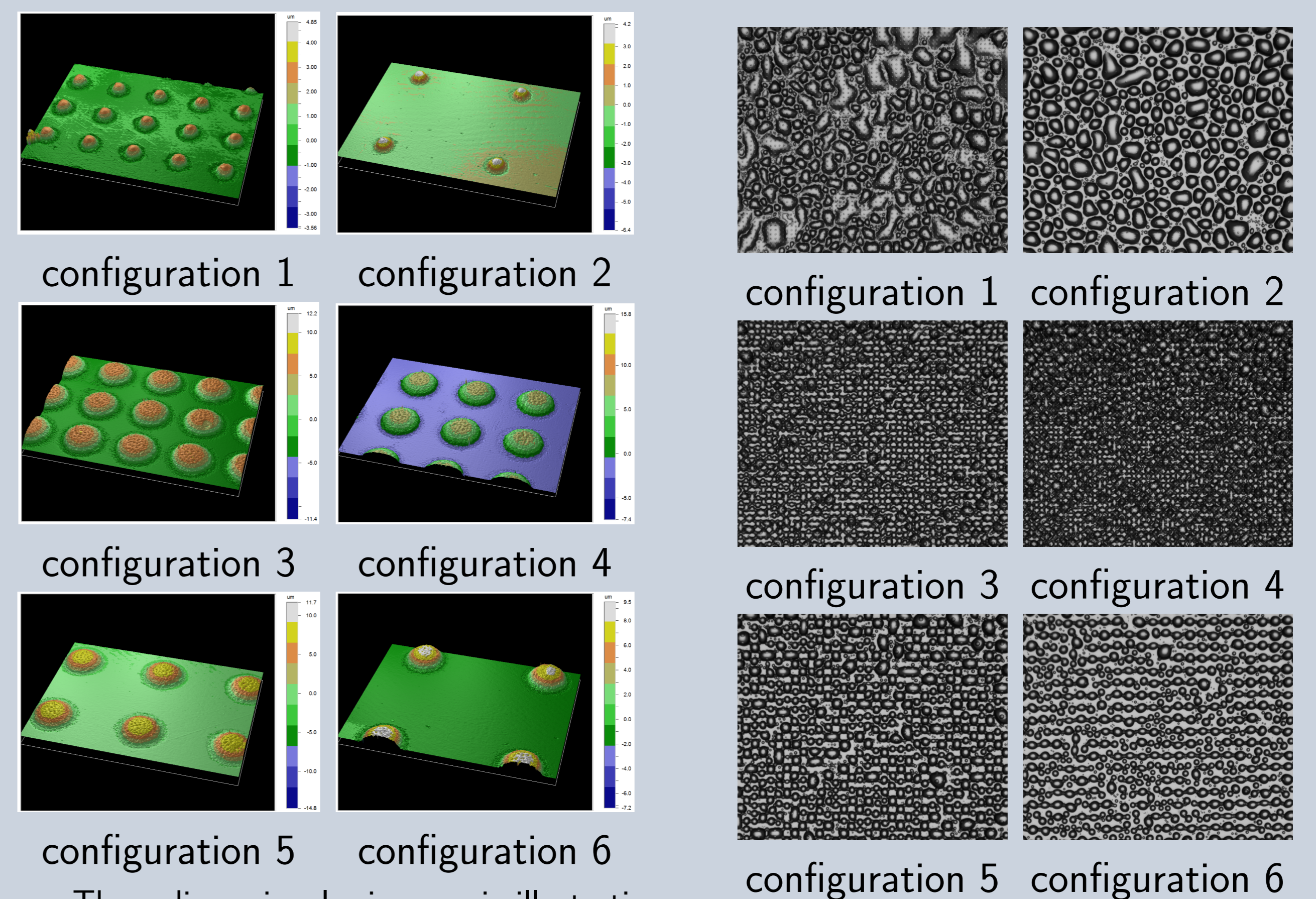


Figure: Three dimensional microscopic illustration of 6 pillared substrates with 50 \times magnification.

Figure: Illustration of 6 pillared surfaces after 1800s.

Table: Mean errors (e_{ave}) of the model in calculating density and radius of the droplets on 6 different textured surfaces. r_t : pillars radius, d_t : distance between the pillars, and h_t : pillars height.

| configuration of pillars | r_t (μm) | d_t (μm) | h_t (μm) | e_{ave} of density (%) | e_{ave} of radius (%) |
|--------------------------|-------------------------|-------------------------|-------------------------|--------------------------|-------------------------|
| configuration 1 | 12.5 | 50 | 3 | 21.28 | -0.62 |
| configuration 2 | 12.5 | 125 | 3 | 3.55 | 9.26 |
| configuration 3 | 25 | 60 | 10 | 3.01 | -2.01 |
| configuration 4 | 25 | 65 | 10 | 13.14 | 0.18 |
| configuration 5 | 25 | 100 | 10 | 11.33 | 1.80 |
| configuration 6 | 25 | 150 | 10 | 7.7 | 5.04 |
| Mean | - | - | - | 10.00 ± 0.68 | 2.28 ± 0.42 |

Conclusions

- ▶ we presented a mathematical model for simulating ellipsoidal droplets growth on textured substrates.
- ▶ The presented model is applied to 6 different pillared surfaces and its mean error is calculated on all the surfaces of about **10%** for droplets density and **2%** for droplets size.

Acknowledgements

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References

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