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Supplementary Materials

Numerical Investigation of the Effect of Symmetry on Evaporation Triggered Elastocapillary Top-Gathering of High Aspect Ratio Micropillars

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Notes S1: Calculation of the Micropillar Displacement (δ): Water.

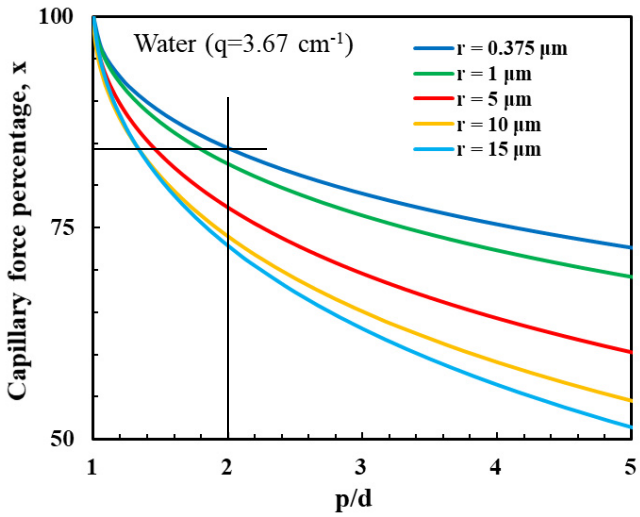

Figure S1. Capillary force percentage of water as a function of pitch over diameter. By knowing the distance of neighbor micropillar and its diameter, capillary force percentage could be found.

Micropillar dimensions

Radius, r = 0.375 µm
Height, h = 9 µm
Micropillar spacing, p = 1.5 µm
Elastic modulus, E = 0.745 and 1.2 GPa

Liquid properties

Liquid: Water
Surface tension, γ = 72.5 mN/m
Contact angle, θ = 60°
n = 24 (points located at 15° interval)

$$F_c = \pi d \gamma_{Water} \sin\theta = 0.1478\ \mu N \tag{S1}$$

$$f_1 = {}^{F_c}/_{n} = {}^{0.1478}/_{24} = 0.0061\ \mu N \tag{S2}$$

For four micropillar in a square arrangement,

Since, p/d =2 and r = 0.375 μm

$$x_1 = 79\ \% = 0.79 \tag{S3}$$

E = 0.745 GPa

$$\delta^* = {}^{64 f_1 h^3}/_{3\pi E d^4} = 0.1294\ \mu m \tag{S4}$$

For $x_2 = 0.59$ (for slight asymmetry)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.1941\ \mu m \tag{S5}$$

For $x_2 = 0$ (for isolated capillary bridging)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.7667\ \mu m \tag{S6}$$

E = 1.2 GPa

$$\delta^* = {}^{64 f_1 h^3}/_{3\pi E d^4} = 0.0803\ \mu m \tag{S7}$$

For $x_2 = 0.59$ (for slight asymmetry)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.1205\ \mu m \tag{S8}$$

For $x_2 = 0$ (for isolated capillary bridging)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.4760\ \mu m \tag{S9}$$

The micropillars located on the edge of the droplet or liquid experience higher force-distributions similar to that for the isolated capillary bridging case and initiate the top-gathering phenomenon which in turn increases the asymmetry.

The calculated micropillar deflection values with E = 0.745 GPa are high meaning that the micropillars are not stable against the capillary forces. However, the calculated deflection values are small with E = 1.2 GPa which is in accordance with the experimental observations of D Chandra et al [1].

Notes S2: Calculation of the Micropillar Displacement (δ): Butyl acetate.

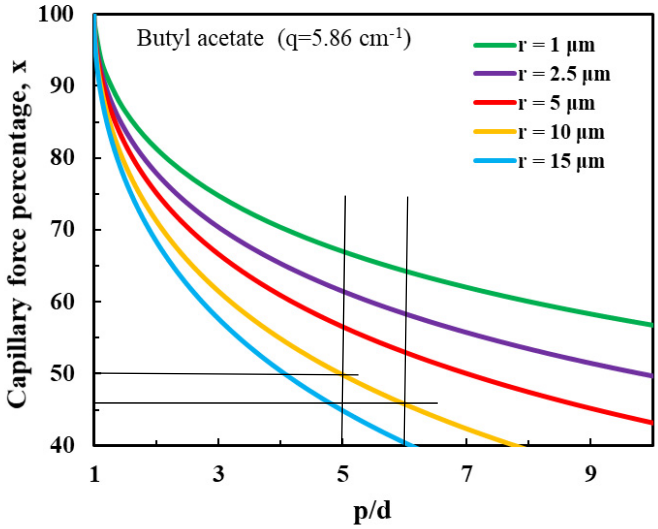

Figure S2. Capillary force percentage of Butyl acetate as a function of pitch over diameter. By knowing the distance of neighbor micropillar and its diameter, capillary force percentage could be found.

Micropillar dimensions

Height, h = 150 µm
Micropillar spacing, p = 100 µm
Elastic modulus, E = 0.0055 GPa

Liquid properties

Liquid: Butyl acetate
Surface tension, γ = 25.1 mN/m
Contact angle, θ = 5.8°
n = 24 (points located at 15° interval)

Radius, r = 5 µm and spacing, p = 100 µm

$$F_c = \pi d \gamma_{\text{Butyl acetate}} \text{Sin}\theta = 0.0796\ \mu\text{N} \tag{S10}$$

$$f_1 = {}^{F_c}/_{n} = {}^{0.0796}/_{24} = 0.0033\ \mu\text{N} \tag{S11}$$

For four micropillar in a square arrangement,
Since, p/d =10

$$x_1 = 42\ \% = 0.42 \tag{S12}$$

$$\delta^* = {}^{64 f_1 h^3}/_{3\pi E d^4} = 1.3828\ \mu\text{m} \tag{S13}$$

For $x_2 = 0.22$ (for slight asymmetry)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 2.0742\ \mu\text{m} \tag{S14}$$

For $x_2 = 0$ (for isolated capillary bridging)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 4.3559\ \mu\text{m} \tag{S15}$$

Radius, r = 5 μm and spacing, p = 200 μm

$$F_c = \pi d \gamma_{\text{Butyl acetate}} \text{Sin}\theta = 0.0796\ \mu N \quad \text{(S16)}$$

$$f_1 = {}^{F_c}/_{n} = {}^{0.0796}/_{24} = 0.0033\ \mu N \quad \text{(S17)}$$

For four micropillar in a square arrangement,
Since, p/d =20

$$x_1 = 20\ \% = 0.20 \quad \text{(S18)}$$

$$\delta^* = {}^{64 f_1 h^3}/_{3\pi E d^4} = 1.3828\ \mu m \quad \text{(S19)}$$

For $x_2 = 0.10$ (for slight asymmetry)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 1.0371\ \mu m \quad \text{(S20)}$$

For $x_2 = 0$ (for isolated capillary bridging)

$$\delta = \approx 7.5(x_1 - x_2)\delta^* = 2.0742\ \mu m \quad \text{(S21)}$$

Radius, r = 10 μm and Spacing, p = 100 μm

$$F_c = \pi d \gamma_{\text{Butyl acetate}} \sin\theta = 0.1592\ \mu N \quad \text{(S22)}$$

$$f_1 = {}^{F_c}/_{n} = {}^{0.0796}/_{24} = 0.0066\ \mu N \quad \text{(S23)}$$

For four micropillar in a square arrangement,
Since, p/d =5

$$x_1 = 50\ \% = 0.50 \quad \text{(S24)}$$

$$\delta^* = {}^{64 f_1 h^3}/_{3\pi E d^4} = 0.1728\ \mu m \quad \text{(S25)}$$

For $x_2 = 0.30$ (for slight asymmetry)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.2592\ \mu m \quad \text{(S26)}$$

For $x_2 = 0$ (for isolated capillary bridging)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.6482\ \mu m \quad \text{(S27)}$$

Radius, r = 10 μm and Spacing, p = 200 μm

$$F_c = \pi d \gamma_{\text{Butyl acetate}} \text{Sin}\theta = 0.1592\ \mu N \quad \text{(S28)}$$

$$f_1 = {}^{F_c}/_{n} = {}^{0.0796}/_{24} = 0.0066\ \mu N \quad \text{(S29)}$$

For four micropillar in a square arrangement,
Since, p/d =10

$$x_1 = 20\ \% = 0.20 \quad \text{(S30)}$$

$$\delta^* = {64f_1h^3}/{3\pi Ed^4} = 0.1728\ \mu m \tag{S31}$$

For $x_2 = 0.42$ (for slight asymmetry)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.1296\ \mu m \tag{S32}$$

For $x_2 = 0$ (for isolated capillary bridging)

$$\delta \approx 7.5(x_1 - x_2)\delta^* = 0.2592\ \mu m \tag{S33}$$

The calculated deflection values for micropillars having radius, r = 5 μm (or diameter, d = 10 μm) are high (> 0.5 μm) for spacings 100 μm and 200 μm, meaning that the micropillars are not stable against the capillary forces.

The calculated deflection values are small (< 0.5 μm for isolated capillary bridging case) for micropillars having radius, r = 10 μm (or diameter, d = 20 μm) for a spacing, p = 200 μm, meaning that the micropillars are stable against the capillary forces for the chosen spacing. However, for spacing, p = 100 μm the deflection of the micropillar is greater than 0.5 μm and hence the micropillars are not stable against capillary forces, which is in accordance with the experimental observations of J Hansson et al [2].

Notes S3: Deflection Calculation Equations

According to Kralchevsky et al. [3] equation S34 may be used to represent the capillary force that is applied to a micropillar while taking into consideration the force distribution:

$$F_c = \pi d\gamma_L \sin\theta \left(\frac{h_c - h_\alpha}{h_\alpha}\right) \tag{S34}$$

By considering this assumption that micropillars top gather (come together) by a deflection of δ in both directions and the capillary curvature is ($q = \frac{1}{Capillary\ length}$), h_c and h_α are defined as equations S35 and S36:

$$h_\alpha = \frac{d.cos\theta}{2}\ \mathrm{Ln}\ (\frac{8}{\gamma q d(1+\sin\theta)}) \tag{S35}$$

$$h_c = \frac{d.cos\theta}{2}\mathrm{Ln}\ (\frac{16}{\gamma^2 q^2 d(\sqrt{(p-\delta)^2 - d^2} + p - \delta)}) \tag{S36}$$

By substituting equations 2 and 3 in equation 1, new capillary force is calculated. The elastic restoring force acting on the deflected micropillar is given as equation S37:

$$F_E = \frac{3\pi E d^4 \delta}{64h^3} \tag{S37}$$

By equalizing equations S34 and S37, elasticity and capillarity are coupled to each other, and the deflection is calculated as shown in equation S38.

$$\frac{3\pi E d^4 \delta}{64h^3} = \pi d\gamma_L \sin\theta \left(\frac{\frac{d.\cos\theta}{2}\ \mathrm{Ln}\left(\frac{16}{\gamma^2 q^2 d\left(\sqrt{(p-\delta)^2 - d^2} + p - \delta\right)}\right) - \frac{d.\cos\theta}{2}\ Ln\left(\frac{8}{\gamma q d(1+\sin\theta)}\right)}{\frac{d.\cos\theta}{2}\ \mathrm{Ln}\ (\frac{8}{\gamma q d(1+\sin\theta)})}\right) \tag{S38}$$

References

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2. Hansson, J.; Yasuga, H.; Haraldsson, T.; van der Wijngaart, W. Synthetic microfluidic paper: High surface area and high porosity polymer micropillar arrays. *Lab Chip* **2015**, *16*, 298–304. https://doi.org/10.1039/c5lc01318f.
3. Kralchevsky, P.; Paunov, V.; Ivanov, I.; Nagayama, K. Capillary meniscus interaction between colloidal particles attached to a liquid—Fluid interface. *J. Colloid Interface Sci.* **1992**, *151*, 79–94. https://doi.org/10.1016/0021-9797(92)90239-i.

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