Electronic Supplementary Material (ESI) for Soft Matter.

Supplementary Information

Temperature-regulated adhesion of drop impact on nano/microtextured monostable superrepellent surfaces

Songlin Shi[1,2], Cunjing Lv[1,2*], Quanshui Zheng[1,2,3]

[1]Department of Engineering Mechanics, Tsinghua University, 100084 Beijing, China

[2]Center for Nano and Micro Mechanics, Tsinghua University, 100084 Beijing, China

[3]State Key Laboratory of Tribology, Tsinghua University, 100084 Beijing, China

Supporting Information.

Visualization of the drop impact under various temperatures of the substrate.
Movie S1: Drop impact on substrate with T_s = 20 ℃.
Movie S2: Drop impact on substrate with T_s = 11 ℃.
Movie S3: Drop impact on substrate with T_s = 10 ℃.
Movie S4: Drop impact on substrate with T_s = 0 ℃.
Movie S5: Drop impact on substrate with T_s = 10 ℃ and a lower impact velocity (We = 3.4).

Supplementary Movies

Movie S1. Drop impact on substrate with T_s = 20 °C.

High-speed imaging of the drop impact at We = 33.4 on the monostable superhydrophobic surface with the substrate temperature T_s = 20 °C. The video is played with 10 fps, while the imaging is recorded with 8,000 fps in the real experiment. The volume of the drop is 3.5 μL. The environment temperature and relative humidity are 20 °C and 10% ± 2%, respectively.

Movie S2. Drop impact on substrate with T_s = 11 °C.

High-speed imaging of the drop impact on the monostable superhydrophobic surface with substrate temperature T_s = 11 °C. The other conditions (Weber number, drop size and frame rates of the imaging, environment conditions) are the same as given in Movie S1.

Movie S3. Drop impact on substrate with T_s = 10 °C.

High-speed imaging of the drop impact on the monostable superhydrophobic surface with substrate temperature T_s = 10 °C. The other conditions (Weber number, drop size and frame rates of the imaging, environment conditions) are the same as given in Movie S1.

* To whom correspondence should be addressed. Email: cunjinglv@tsinghua.edu.cn

Movie S4. Drop impact on substrate with T_s = 0 °C.

High-speed imaging of the drop impact on the monostable superhydrophobic surface with substrate temperature T_s = 0 °C. The other conditions (Weber number, drop size and frame rates of the imaging, environment conditions) are the same as given in Movie S1.

Movie S5. Drop impact on substrate with T_s = 10 °C and a lower velocity (We = 3.4).

High-speed imaging of the drop impact on the monostable superhydrophobic surface with substrate temperature T_s = 10 °C and We = 3.4. The other conditions (drop size and frame rates of the imaging, environment conditions) are the same as given in Movie S1.

Section S1. Characterization of the Monostability

The wettability of the monostable SHSs are characterized by checking whether the following criterion of the spontaneous Wenzel-to-Cassie (W2C) transition[1] could be satisfied

$$\frac{1-f}{r-f} < -\cos\theta_{\mathrm{r}}, \tag{S1}$$

denoting f the solid-liquid area fraction and r the roughness factor. In our experiment, the parameters of the micropillared substrate a = 25 μm, b = 75 μm and h = 100 μm lead to $f = a^2/(a+b)^2$ =0.06 and $r = 1+4ah/(a+b)^2$ = 2.0, which means the requirement of the monostability could only be satisfied when $\theta_r \geq 119°$. In our test, the receding contact angle of the Glaco-treated surface is 152 ± 2°, which is much higher than 119°, suggesting that our substrate owns the wetting property of monostability.

Section S2. Vapor Diffusion in the Nanotextures

To estimate the time scale for the water vapor fully fills the room of the nanotextures, we quantify the mass flux through the liquid-vapor interface in terms of the following equation[2]

$$J = -D_{\mathrm{diff}}\frac{\partial C}{\partial x} \approx D_{\mathrm{diff}}\frac{C_{\mathrm{S}}-C_{\infty}}{L} \approx \frac{D_{\mathrm{diff}}C_{\mathrm{S}}}{L}(1-R_{\mathrm{H}}), \tag{S2}$$

where J and D_{diff} are the evaporation rate and the diffusion coefficient of water, respectively. R_{H} is the relative humidity and L is the characteristic length of the nanotextures. C_{S} is the concentration of the saturated vapor and $C_{\infty} = C_{\mathrm{S}} \cdot R_{\mathrm{H}}$ is the concentration far from the evaporating liquid. By integrating Eq. (S2) with time, the relative humidity can be obtained

$$R_{\mathrm{H}}(t) = 1 - (1 - R_{\mathrm{H0}}) e^{-t/\tau_{\mathrm{diff}}}, \tag{S3}$$

where R_{H0} is the humidity of the ambient air and τ_{diff} is the characteristic evaporation time. The diffusion of the water vapor in the air can be expressed by using the Fick's second law[2]

$$\frac{\partial \varphi}{\partial t} = D_{\mathrm{diff}} \frac{\partial^2 \varphi}{\partial x^2}, \tag{S4}$$

where $\varphi = \varphi\ (x, t)$ is the function of the distance x and time t. Supposing that $\varphi\ (x, t)$ is linear with x and t, we can obtain the following approximation

$$t \approx \frac{x^2}{2D_{\mathrm{diff}}}, \tag{S5}$$

where x is the mean diffusing distance with the elapsed time t, denoting $\tau_{\mathrm{diff}} = t$. Here, we assume that x is equal to the nanoparticle characteristic size $L \sim 80$ nm. Since $D_{\mathrm{diff}} = 24.2$ mm^2/s, we can calculate the elapsed time $\tau_{\mathrm{diff}} \approx 0.1$ ns. In our experiment, the value of R_{H0} is about 10%, so approximately $R_{\mathrm{H}}(t) \approx 1 - \exp(-t/\tau_{\mathrm{diff}})$, which means that the timescale t at the nano-second scale (see Eq. S3) is already large enough to result a high humidity (i.e. $R_{\mathrm{H}}(t) \approx 1$) for water vapor to fill the space of the nanotextures.

Section S3. Drop Impact without Wetting State Transition

Here, we demonstrate that under the lower impact velocity, i.e. We = 3.4, the drop cannot penetrate the micropillars, and there is no micro-Wenzel contact region during the impact process. The experiments are carried out on substrate with $T_{\mathrm{s}} = 10$ °C. As shown in Figure S1a, there is only a micro-Cassie contact and finally the drop does not stick the surface, whereas at a higher impact velocity We = 33.4 (Figure S1b), a sticky Wenzel contact occurs and the drop sticks the microtextures. Compared with the amount of condensation Q_W occurring in the Wenzel contact region (i.e. the side walls and the valleys of the micropillars), the amount of the condensation Q_T occurring on the top of the micropillars is much less. In fact, we could estimate the ratio, i.e., $Q_T/Q_W \approx a^2/[(a+b)^2+4ah] = 3.125\%$. Based on that, Q_W is too small to be neglected. This text suggests that the micro-Wenzel contact region is the main source accounting for the adhesion.

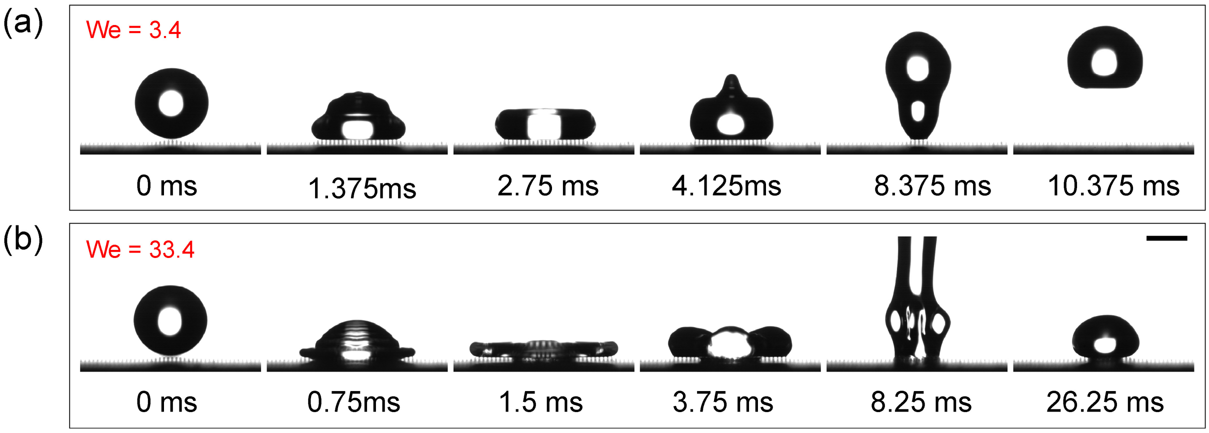

Figure S1. Comparison of drop impact on substrates with different impact velocities. The drop with (a) We = 3.4 cannot penetrate the micropillars, which is distinct from its counterpart, a drop with (b) We = 33.4 that penetrates the micropillars and finally sticks the surface. The temperatures of the substrates are $T_s = 10$ °C. The ambient temperature and relative humidity are 20 °C and 10% ± 2%, respectively. The scale bar represents 1 mm.

References

1 Y. Li, D. Quéré, C. Lv and Q. Zheng, Monostable Superrepellent Materials. *Proc. Natl. Acad. Sci. U.S.A.*, 2017, **114**, 3387-3392.

2 P. W. Atkins, J. De Paula and J. Keeler, *Atkins' physical chemistry*, Oxford university press, 2018.