Effects of Surface Wettability on the Dewetting Performance of Hydrophobic Surfaces

Jiang Li, Wenjun Wang,* Xuesong Mei, and Aifei Pan

ABSTRACT: We studied the impact dynamics of a droplet on two types of surfaces, i.e., nanostructured/hierarchical (NS/HS) surfaces, with different extents of hydrophobicity. It was found that the contact time is related to wetting hysteresis. It can be concluded that wetting hysteresis plays a significant role in the contact process of bouncing drops based on the work done against resistance produced by contact angle hysteresis (CAH). For similar surface roughness, the work done by CAH dominates, and a lower CAH creates a smaller contact time. Compared with NS surfaces, the energy stored during the Cassie−Baxter/Wenzel state transition because of the more pronounced air pocket formation provides the upward kinetic energy, resulting in rapid detachment of a droplet from HS surfaces. Thus, HS-3 has a smaller contact/elongation time (∼8/2 ms) because of the enhanced air pocket formation and more favorable wettability (larger contact angle (CA) and smaller contact angle hysteresis (CAH)) than other surfaces. In addition, the results show that surface morphology affects the contact time of bouncing drops mainly by influencing the elongation stage. For different Weber numbers (We), the upward energy storage dominates and results in different varying trends of contact time with We for NS-3 and HS-3. For further study, the morphology evolution of bouncing drops with We was also investigated in detail. The results show that a satellite droplet is launched in a certain We range because of high adhesion resulting from the Cassie−Baxter/Wenzel state transition. These findings provide guidelines for the preparation of surfaces for both self-cleaning and anti-icing purposes.

INTRODUCTION

Superhydrophobic surfaces that promote rapid drop detachment have received much attention in both industrial and academic activities because of their anti-icing, drag reduction, and self-cleaning properties.1−12 The transport of a water drop on a solid is a complex process owing to the nature of contact between the solid and the liquid.13−22 In addition, the contact takes place mostly under dynamic circumstances.23,24,29,33−36 Drops in motion impact a solid surface, spread, and subsequently retract.23,24 The next event depends on surface wettability. On a hydrophilic surface, the droplet wets the surface; on a hydrophobic surface, the droplet is fully detached from the substrate or partially sticks to the substrate depending on energy dissipation in the contact stage.27−29 In both cases, the resulting phenomenon mainly depends on the initial kinetic energy of bouncing drops and surface conditions, i.e., the extent of hydrophobicity, surface roughness, and temperature.14,18,21,30−33

The contact time, which typically represents the energy conversion between a droplet and a surface, is considered important.32,34 Therefore, it has been the subject of extensive experimental and theoretical studies and is generally advantageous to minimize the contact time of bouncing drops. The contact time of bouncing drops on a flat nonwetting surface is independent of impact velocities, $\sim (\rho D^3_0/\sigma)^{1/2}$, but depends on the droplet size instead.18,25,35,36 Recently, surface textures were considered when describing the impact events of drops because they favor a higher static contact angle (SCA). It was therefore designed, and a rapid detachment was promoted and realized.4,16,23,31,33 In addition to CA, the contact time is also affected by contact angle hysteresis (CAH), which defines the adhesion and mobility of droplets on nonwetting surfaces to some extent.3 However, the role of CAH was mostly neglected. Setting a liquid droplet in motion requires non-negligible forces to overcome the force opposing the motion generated by CAH.37,38 Song et al. reported the fabrication of surfaces with droplet pancake bouncing and controlled the bouncing state. The contact behaviors could be controlled by adjusting
the inclination angle of pillars. Liu et al. reported the fabrication of microcone arrays to promote fast detachment of an applied droplet on contact surfaces. These studies determined the potential link between surface morphology and contact time. In some studies, the CAs and CAHs were measured but mainly as a byproduct for studying the impact process. Aussillous reported that the CAH was crucial for preventing the motion of a droplet on a surface, and thus, a liquid marble was used to reduce the adhesion to the surface. Mishchenko et al. revealed the mechanism of how the dynamic wetting behaviors change in a cooling environment on a tilted surface. Zhang et al. fabricated superhydrophobic surfaces with two-tier roughness and evaluated the drop impact behavior on oblique surfaces. They related the different contact behaviors to different solid fractions. The CAHs were measured, but their role in affecting the contact process was ignored. Shen et al. reported the potential relationship between the wetting hysteresis and contact time of a bouncing droplet on planar nonwetting surfaces. The contact behaviors were not studied in detail. The study by Zhang and Shen also demonstrated that the contact behavior has no direct relationship with the static CA. Despite all of the exciting advances, the effect of different textured surfaces on the contact process and the underlying mechanism for impinging droplets on nonwetting surfaces still need to be evaluated. Considering the practical applications, the contact time of a water droplet impacting on textured surfaces should be measured and analyzed in tandem with SCA and CAH, and the contact time should be decoupled so as to reveal the internal and underlying relationship.

In this paper, nanostructured/hierarchical surfaces (NS/HS surfaces) with different extents of hydrophobicity were fabricated. Based on the designed different classes of hydrophobic surfaces, we fully evaluated the SCA, CAH, and contact time of a bouncing droplet on nonwetting surfaces. The contact behaviors were not studied in detail. The study by Zhang and Shen also demonstrated that the contact behavior has no direct relationship with the static CA. Despite all of the exciting advances, the effect of different textured surfaces on the contact process and the underlying mechanism for impinging droplets on nonwetting surfaces still need to be evaluated. Considering the practical applications, the contact time of a water droplet impacting on textured surfaces should be measured and analyzed in tandem with SCA and CAH, and the contact time should be decoupled so as to reveal the internal and underlying relationship.

In this paper, nanostructured/hierarchical surfaces (NS/HS surfaces) with different extents of hydrophobicity were fabricated. Based on the designed different classes of hydrophobic surfaces, we fully evaluated the SCA, CAH, and contact time of a bouncing droplet on nonwetting surfaces. To elucidate the underlying mechanism and the relationship between the contact time of an impacting droplet, the contact time on various surfaces with different impacting velocities was first obtained and then decoupled. The results show that for similar surface roughness, the work done by CAH dominates and a lower CAH creates a smaller contact time. In addition, surface morphology significantly affects the elongation stage of bouncing drops. For different Weber numbers (We), the upward energy storage dominates and results in different varying trends of contact time with We for NS-3 and HS-3. To better observe the impact, the morphology evolution (i.e., diameter and height) for HS-3 was obtained, and its mechanism was further elucidated. This study provides strong support for practical applications of nonwetting surfaces.

## EXPERIMENTAL SECTION

A micro–nanohierarchy was fabricated using the laser swelling technique and chemical growth of ZnO nanorods successively. First, a microstructure array was prepared on the substrate by dual-layer fabrication using femtosecond laser swelling, as shown in Figure 1a. Photolysis of the dye material of the underlying layer and molecular relaxation of the upper layer are responsible for the formation of a convex structure. By adjusting the laser parameters, the morphology of the convex structure could be controlled. Next, after PDMS molding and UV irradiation of a UV-curable resin, a microstructure array was obtained (Figure 1b–d). Then, the micro–nanohierarchy was further obtained using a chemical growth method (Figure 1e–f).

### Preparation of Samples.

Poly(methyl methacrylate) (PMMA) crystals (20 g, available at Aladdin) were added to chlorobenzene (80 g), and the mixture was stirred using a magnetic stirrer until the crystals were fully dissolved. The obtained PMMA solution was then carefully deposited on an acrylic plate (20 × 20 mm², available from Taobao), and the thickness of sample was controlled by the volume of the solution. Finally, the sample was placed in a sealed environment and dried at room temperature for 12 h.

### Preparation of Microstructures.

A femtosecond laser with a wavelength of 800 nm and a repetition frequency of 1 kHz was used as the light source for irradiation. The movement of sample was accurately controlled using a motorized translation stage (DaHeng Photoelectric Technology). The laser beam was successively passed through an attenuator, a diaphragm, a half-wave plate, a beam-splitting prism, and an objective lens and finally focused on the sample. The laser power and irradiation time are 21 mW and 1.5 s, respectively. The obtained height and diameter of the convex structure are 11 and 45 μm, respectively.

### Fabrication of the Micro–Nanohierarchy.

Poly(dimethylsiloxane) (PDMS) with a certain mass ratio (10:1) was poured on the sample obtained in the first step. After curing fully, the replica was peeled off. The solvent-free UV-curable epoxy resin (NOA) was then deposited on the obtained replica and fully cross-linked for 1 min under UV light irradiation. The master mold was released, and a convex array was obtained. Subsequently, a 20 nm ZnO seed layer was sputtered on the convex surface. Hexamethyldisilazane (250 mL, 2.8% (w/v)) was mixed with zinc nitrate (250 mL, 5.94% (w/v)), and the mixture was stirred using a magnetic stirrer for 20 min. Then, the sample with the ZnO seed layer was immersed in the prepared mixture and kept at 90 °C using a water bath (HH S11-4-S, Longyue Instruments Inc., Shanghai, China) for 20, 30, 40, and 50 min. After the reaction was completed, the sample was removed, washed repeatedly with excess deionized water to remove any unreacted materials from the ZnO surface, placed in a clean oven, and dried at 50 °C for 30 min. Thus, a micro–nanohierarchy was obtained. By controlling the reaction time,
nanostructures and micro–nanohierarchies with different morphologies were obtained. In the experiment, the reaction time ranges from 20 to 50 min with an interval of 10 min. The process for fabrication of micro- and nanostructures is described in the literature.40 The morphology of fabricated structures with a bath time of 20 min is shown in Figure 3. The wettability of various substrates was characterized using a Data Physics OCA 20 system at ambient temperature by measuring the advancing contact angle (ACA), receding contact angle (RCA), sliding angle (SA), and SCA of water droplets. For measuring CA, a reference droplet of 5 μL was gently deposited on the surface. For measuring CAH, the ACAs and RCAs were measured at the front and back of the droplet moving along the tilted surface, respectively. All of the measurements were repeated three times, and the results are shown in Table 1. The structures were characterized using a scanning electron microscope (HITACHI).

**Setup for the Impact Experiment.** Figure 2 shows a schematic of the experimental setup. A constant-volume frame rate of 4000. A computer was used to control the motion of the motorized stage and the action of the camera.

**RESULTS AND DISCUSSION**

Figure 3a–d shows that the nanostructures have different lengths/diameters of 202/127, 504/108, 577/97, and 621/90 nm. The obtained height and diameter of the convex structure are 11 and 45 μm, respectively. The space in the experiment was set as 60 μm by controlling the motion stage. For hierarchical structures, the on-top nanostructures have similar morphology to their nanostructured counterpart (treated with the same reaction time).

**Nonwettability of Fabricated Surfaces.** To evaluate the wetting properties of these surfaces, the contact angles, i.e., SCA, SA, CAH, were measured. The results are shown in Table 1. The values are averaged from three measurements. CAH is defined as the difference between ACA and RCA. The work by Zhang and Shen demonstrated that the impact contact time has no direct relationship with ACA for hydrophobic surfaces with similar roughness.43,44 For superhydrophobic surfaces, the variation in CA is acceptable, and the surfaces were used for conducting the drop impact experiment.

Surface morphology and chemical modification are the main factors affecting surface wettability. To evaluate the effect of surface structures on the wettability and mobility of a droplet on a solid, the CAs and CAHs on flat and textured surfaces were measured after the C4F8 gas plasma treatment; the results are shown in Table 1. For a flat surface, the CA is $\sim 113^\circ$. The addition of nano- and microscale textures on the surface significantly improves the wettability (higher CAs) and mobility (lower CAHs and SAs) of droplets on the substrates due to the formation of an air pocket. According to our previous study, NS-3 and HS-3 are beneficial for hydrophobicity because of a relatively large amount of air trapped underneath the water. For NS-1 and NS-2, the sparse distribution of nanorods results in a minor improvement in the water repellent performance.40 This is because, for the two surfaces, the sparse distribution of nanostructures promotes the wetting of the solid surface; therefore, a lower CA and a higher CAH were found for a lower $\phi$. The values of corresponding CA and CAH are 132/26 and 133/20°, respectively (as shown in Table 1). A similar trend was also observed for HS-1 and HS-2. However, for NS-4 and HS-4, the nanorods became overcrowded. This affects the formation of air pockets; thus, a decreased CA and an increased CAH are observed. Moreover, the CAs of a water droplet on HS surfaces are higher than those on the corresponding NS surfaces, indicating that the microstructures play a role in wettability.
modification and enhances the air pocket formation. In addition, a lower adhesion force is observed for HS surfaces (because a lower CAH and SA are observed) because the contact area is reduced, which benefits the mobility of an impacting droplet. For HS-3, a smaller solid fraction (~4%) results in a higher CA of 168° and a lower CAH of 9.7° compared with other surfaces.

To evaluate better the wetting state of textured surfaces, the experimental CAs and SAs on HS surfaces were plotted; the theoretical CAs for Cassie-Baxter and Wenzel models were also calculated and plotted, as shown in Figure 4a. This showed that the experimental CAs (blue dotted line) reside between the two thresholds of Cassie CAs (red dotted line) and Wenzel CAs (pink dotted line). The order CA_{Cassie} > CA_{Experiment} > CA_{Wenzel} probably results from the partial penetration of liquid into the gaps of the structures. This leads to the metastable wetting state of droplets (partial magnification in Figure 4b2). Figure 4b shows a schematic of three wetting states for different hierarchical surfaces. The largest contact area between the droplet and the surface is given in the Wenzel state (Figure 4b1, which exhibits a continuous wetting interface) but is reduced in the metastable state (Figure 4b2) and minimized in the Cassie state (partial magnification in Figure 4b3). In practical cases, the droplets on a textured surface tend to show a metastable state. For the different surfaces, the lower the contact area of applied water droplets, the stronger the air pocket effect, reducing the CAH, SA, and adhesive force. Thus, the SAs have the same varying trend as the solid fraction.

Outcomes of the Normal Drop Impact and Related Mechanism. Performance of Fabricated Surfaces. The timescales of various contact phases between an impact droplet and textured surfaces are important because they determine the energy conversion in practical applications. In the study, to characterize the dewetting performance, the collision dynamics of drops (We = 60) on different surfaces were observed. Figure 5a shows the evaluation of bouncing drops on the prepared substrates. The drop responds to the surfaces in a similar manner for NS-3 and HS-3. The image sequences show a water droplet upon contact, maximum spreading, crown formation, and bouncing off the surface. Notably, the drops retract violently, leading to the ejection of satellite droplets from the surface except in one case for HS-3. For further observation of the contact process, the timescales of τ_{contact} were decoupled as τ_{contact} = τ_{spread+retract} + τ_{elongate}, where τ_{spread+retract} is the time interval between the time when the impact starts and the time when the crown formation ends and τ_{elongate} is the time interval between the crown formation and full detachment from the surface. The time evolution was divided based on the following concept: for the same initial kinetic energy of the impacting droplet, the length of τ_{elongate} represents the kinetic energy left when leaving the surface. Figure 5b shows the relationship between the timescales and CAs of fabricated structures. Previous studies indicate that inertia and capillarity are antagonistic and provide a contact time of τ_{0} \sim (\rho D^3/\sigma)^{3/2}, where \rho = 1000 kg m^{-3}, surface tension \sigma = 72 \times 10^{-3} N m^{-1}, and D = 2.12 mm. In the experiment, for NS-1, NS-2, NS-3, and NS-4, the corresponding values of τ_{NS} are 3.57τ_{σ0}, 3.28τ_{σ0}, 2.7τ_{σ0} and 2.89τ_{σ0}, respectively. For HS-1, HS-2, HS-3, and HS-4, τ_{NS} values are 0.84τ_{NS-1}, 0.86τ_{NS-2}, 0.76τ_{NS-3}, and 0.91τ_{NS-4}, respectively. The contact times of HS surfaces are reduced by factors of 1.19, 1.16, 1.31, and 1.1 than those of NS counterparts (i.e., structures fabricated with the same reaction
previously reported results4,16,34 but larger than the tapered bouncing did not appear, the contact time was comparable to bouncing drops in addition to CA. Notably, although pancake CAH is the predominant factor a

Also, significant improvements in the reduction of contact time (~8 ms) were observed for HS-3 with the lowest CAH. The variation trends of the contact time and CAH indicate that CAH is the predominant factor affecting the contact time of bouncing drops in addition to CA. Notably, although pancake bouncing did not appear, the contact time was comparable to previously reported results31,16,34 but larger than the tapered arrays.31 This can be attributed to the small curvature of microstructures, degrading their performance of contact time reduction. In addition, it was observed that the values of τ_{spread-retract} are almost constant (~6 ms) for NS and HS surfaces (the black column in Figure 5b), yet τ_{elongation} (red column) is very different and Δτ_{contact} ≈ Δτ_{elongation} indicating that surface structures affect the contact time of bouncing drops mainly by influencing the elongation stage. The contact times on HS surfaces are lower than their NS counterparts. For NS/HS surfaces, the contact time varies in a similar manner to CAH.

![Figure 5](https://dx.doi.org/10.1021/acsomega.0c04106)

**Figure 5.** (a) Selected moments for droplets impacting on NS-3 and HS-3. The moments include upon contact, maximum spreading, elongation initiation (starts from crown formation), and detach from the surface. In all cases, D₀ = 2.12 mm and We = 60. (b) Relationship between contact timescale and hydrophobicity for NS/HS surfaces. The values of τ_{spread-retract} are almost constant (~6 ms) for NS and HS surfaces (see the black column). Yet, τ_{elongation} (red column) is very different and Δτ_{contact} ≈ Δτ_{elongation} indicating that surface structures affect the contact time of bouncing drops mainly by influencing the elongation stage. The contact times on HS surfaces are lower than their NS counterparts. For NS/HS surfaces, the contact time varies in a similar manner to CAH.

\[ W = W_{\text{spread}} + W_{\text{retract}} = \frac{1}{8} \pi D_{\text{max}} \sigma_{lg} (\cos \theta_R - \cos \theta_A) \]

where σ_{lg} is the liquid/gas surface tension, and D_{max} is the maximal diameter.

Furthermore, the difference in the cosines of ACA and RCA is related to the difference of those for a smooth surface, ACA₀ and RCA₀, as follows37

\[ \cos \theta_A - \cos \theta_R = R_i (1 - f_{LA}) (\cos \theta_A - \cos \theta_{R,0}) + H_i \]

where \( H_i \) is the effect of surface roughness, \( f_{LA} = 1 - \varphi_i \), where \( \varphi \) is the solid fraction (as shown in Table 1). Equation 2 shows that an increase in \( f_{LA} \) results in an increase in CA (\( \cos \theta \rightarrow -1, \theta \rightarrow \pi \)) and a decrease in \( (\cos \theta_A - \cos \theta_R) \). For \( f_{LA, HS} > f_{LA, NS} \), \( (\cos \theta_A - \cos \theta_{R, HS} < (\cos \theta_A - \cos \theta_{R, NS}) \). In addition, for NS and HS surfaces at the same We of 60, the maximum spreading diameter varies slightly (while it is slightly larger on HS surfaces). According to eq 1, \( W_{HS} < W_{NS} \), i.e., for HS surfaces, less work was done by CAH. On the other hand, the penetration of droplets between the gaps of microstructures results in energy storage during spreading and reverses back to upward kinetic energy at the subsequent retraction stage. This results in a rapid detachment of impacting droplets on HS surfaces compared with the NS surfaces. For a similar surface roughness (NS or HS surfaces), the work done by CAH dominates and a lower CAH creates a smaller contact time. Thus, the water droplet can bounce off the NS-3 and HS-3 surfaces with a smaller contact time because of the lower CAH. Compared with NS surfaces, the energy stored during the Cassie–Baxter/Wenzel state transition provides upward kinetic energy because of the more pronounced air pocket formation, resulting in the rapid detachment of a droplet from HS surfaces. Thus, HS-3 has a smaller contact/elongation time (~8/2 ms) because of the enhanced air pocket formation and more favorable wettability (larger CA and smaller CAH) than other surfaces. This is further verified by the observation of τ_{elongation}. A smaller CAH shows a shorter τ_{elongation} indicating higher kinetic energy when starting the elongation stage. Therefore, smaller contact time can be expected.

The aforementioned results show that CAH plays a significant role in the contact process of bouncing drops on textured surfaces. For NS surfaces, the CAH dominates due to insignificant upward energy storage, whereas for HS surfaces, the cooperation of both CAH and upward energy storage contributes to the obvious reduction in the contact time. A comparison of these surfaces indicates that the impact droplets on HS-3 bounce off rapidly because of favorable wettability (higher CA and lower CAH) and upward energy stored due to the presence of a microscale array. This shows that hierarchical surfaces with a lower CAH can better detach the water droplet than nanostructured surfaces.

**Effect of We on Impact Dynamics.** The We was systematically varied from 12 to 60, and the timescales on NS-3 and HS-3 were determined. Figure 6a,b shows the typical behavior of droplets impacting NS-3 and HS-3 at different We values of 12, 36, and 60, respectively. At a small We, the droplet experiences axisymmetric evolution, i.e., spreading, retraction, and oscillation after rebound without sticking onto it. This is similar to what was observed for the effect of water droplets on hydrophobic surfaces. Furthermore, the drop spreads radially for a short distance prior to inward retraction...
and vertical elongation. In this regime, the droplet contacts with the surface for a relatively long time. With the increase in We, the fast impact results in unstable behavior and oscillation during the elongation stage. The shape of the droplet changes irregularly, and a satellite droplet starts to produce at a higher We of 27. For HS-3, the deformation experiences a similar behavior as NS-3. However, for a higher We (60), the deformation and oscillation are much quieter for HS-3. A satellite droplet was not produced for a We of 60 but at a lower We of 36.

Figure 6c,d shows the dependence of three timescales on We for NS-3 and HS-3, respectively. \(\tau_{\text{spread-retract}}\) shows a small increasing trend with varying We for NS-3 and HS-3 (\(\approx 5\) to 6 ms). For NS-3, a small steplike variation in the contact time appears at a We of 36. However, for HS-3, the contact time depends on We; it decreases continuously and more remarkably with We. For We \(= 12, 36, \text{and } 60\), the contact times of \(\tau_{\text{HS}}\) are 0.93, 0.95, and 0.76\(\tau_{\text{NS}}\), respectively. At a larger We, the hierarchical surface exhibits better dewetting performance with a lower contact time.

A dynamic diameter reflects the deformability of impact drops, and it is crucial to understand better the dynamic characteristic of bouncing drops. Figure 7a shows the \(D_t/D_0\) evolution for HS-3. The instantaneous diameter first increases and the subsequent retraction process leads to a decrease in the normalized diameter. Figure 7b shows the normalized maximum diameter \(D_{\text{max}}/D_0\) for different values of We. Formative research shows that the normalized maximum diameter of impacting droplets on a solid surface can be represented as \(\text{We}^{1/4}\) due to volume conversation.\(^{15,48}\) In the experiment, the values follow \(\sim \text{We}^{1/4}\), indicating that the spread of droplets is capillary-dominated.\(^{48}\) Figure 7c shows the typical height variation of droplet dependence on We. For a small We of 12−30, the vertical elongation becomes more pronounced with an increase in We (a higher slope) because of increased dynamic pressure sustained by hierarchical structures. When We \(\approx 36−48\), the drop becomes highly elongated and produces a singular vertical satellite before detachment. The separated droplet is not produced by fragmentation, yet producing a continuous reduction in contact time. Interestingly, a further increase in We will result in the disappearance
of the satellite droplet, and the vertical extension becomes less violent (the slope becomes smaller).

Previous studies show that $t_{\text{spread}}$ is independent of $W_e$ for nanostructured and hierarchical surfaces. In our experiment, $t_{\text{spread+retract}}$ shows a slightly increasing trend for NS-3 and HS-3. For HS-3, a higher impact kinetic energy results in an increase of $t_{\text{spread+retract}}$ due to a larger maximum spreading diameter, but it also causes an obvious reduction in $\tau_{\text{elongation}}$. However, $\Delta \tau_{\text{elongation}}$ overwhelmed $\Delta t_{\text{spread+retract}}$, thus, a continuous reduction in the contact time was found for HS-3. Figure 7d shows the schematic of contact interfaces on the structured surfaces of bouncing droplets with different velocities. The droplet is in the Cassie–Baxter state when deposited gently on the surface; thus, the contact time is less dependent on impact velocities. When impacting at a high $W_e$, the enhanced penetration of drops into the gaps of surfaces, on the one hand, causes a larger CAH, resulting in more energy dissipation during the process. On the other hand, an amount of energy is restored and provides some upward kinetic energy (no pancake bouncing occurs owing to insufficient energy storage). For the HS surface, the latter dominates the process, and the enhanced effect of upward energy results in a continuous reduction in the contact time with $W_e$ for HS-3. However, when leaving the substrate, the penetration also provides adhesion to the substrate (mainly because of nanostuctures). Thus, the bouncing droplet becomes highly elongated and produces a satellite droplet. For NS-3, the variation in upward energy storage is insignificant because of the smaller size of nanostructures; thus, the contact time varies slightly with increasing $W_e$. For a certain $W_e$, the penetration of the droplet is saturated, resulting in an almost unchanged variation in CAH and restored energy. Consequently, the contact time becomes independent of $W_e$ again. In addition, the vertical extension becomes smaller, producing no satellite droplet in this $W_e$ regime. In our experiment, the corresponding $W_e$ range on NS-3 is much shorter than that on HS-3 and the saturation condition is not reached for HS-3. This can be attributed to a larger amount of trapped air for HS-3 than that for NS-3.

## CONCLUSIONS

The impact behaviors on eight classes of hydrophobic surfaces are compared and discussed. For NS surfaces, the effect of CAH dominates, while for HS surfaces, the combined effect of a lower CAH and additional upward energy accounts for the smaller contact time. In addition, the smallest contact time of $\sim 8$ ms was observed on HS-3 because of the favorable wettability and upward energy provided. For varying $W_e$, the variation in the contact time was due to the dynamic wetting state. The produced larger upward vertical kinetic energy dominates the process, resulting in the morphological evolution of bouncing drops with $W_e$. On a nonwetting surface, the textured surfaces with low CAH and high energy storage capacity benefit the rapid detachment of bouncing drops. This provides a guideline to further reduce and minimize the time to obtain an optimized morphology with better performance.

## AUTHOR INFORMATION

**Corresponding Author**

Wenjun Wang — State Key Laboratory for Manufacturing System Engineering, Xi’an Jiaotong University, Xi’an 710054, China; orcid.org/0000-0002-2562-4077;

Phone: 13891435862; Email: wenjunwang@mail.xjtu.edu.cn

**Authors**

Jiang Li — College of Mechanical and Electronic Engineering, Northwest A&F University, Yangling 712100, China; State Key Laboratory for Manufacturing System Engineering, Xi’an Jiaotong University, Xi’an 710054, China

Xuesong Mei — State Key Laboratory for Manufacturing System Engineering, Xi’an Jiaotong University, Xi’an 710054, China

Aifei Pan — State Key Laboratory for Manufacturing System Engineering, Xi’an Jiaotong University, Xi’an 710054, China

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.0c04106

**Notes**

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