Spontaneous dewetting of a hydrophobic micro-structured surface

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Abstract
Inspired by recent experimental observations and natural phenomena that spontaneous dewetting transition occurs on a hydrophobic micro-structured surface, a thermodynamic model of a condensed water droplet on a micro-pillar arrayed surface is established in order to disclose the mechanical mechanism. Based on a general model of an arbitrary-shaped micro-structured surface, surfaces with conical, rectangular and parabolic micro-pillars are investigated. A critical water droplet volume is found, beyond which dewetting transition can be realized. The effect of the micro-pillar’s size and intrinsic contact angle on the free energy difference and critical water droplet volume are further studied. The theoretical model may provide a possible explanation for the abnormal Wenzel wetting state of condensed water droplets on lotus leaves and the anti-fogging behavior of a mosquito’s compound eyes. The present results should be very useful for the biomimetic design of functional dewetting surfaces in practical applications.

Keywords: micro-pillar arrayed surface, dewetting transition, energy difference, critical droplet volume, biomimetic design

(Some figures may appear in colour only in the online journal)

1. Introduction
Different from the wettability on a perfectly smooth surface, water droplets can have multiple wetting modes on rough surfaces depending on the surface chemistry and the roughness size and topography, each corresponding to respective stable or metastable state [1–3]. The basic wetting states of water droplets on rough surfaces have been established for many years by Wenzel [4] and Cassie and Baxter [5]. The Wenzel model is characterized by the penetration of a water droplet into the texture of the rough surface; while in Cassie–Baxter wetting state, water droplet is suspended on top of the roughness features, with air trapped underneath. It has been shown that both the Cassie–Baxter and Wenzel wetting regimes can coexist on the same rough surface. Understanding and realizing wetting transition, especially spontaneous transition, between different wetting modes is highly desired and of crucial importance for a wide range of practical applications, such as self-cleaning...
superhydrophobicity with large contact angle (ting feature of water droplets on lotus leaves is the well-known observed on a same hydrophobic surface. For example, the wet-Baxter and Wenzel wetting states have been experimentally designing water-repellent surfaces [1, 14–16].

Depending on how to deposit water droplets, both Cassie–Baxter and Wenzel wetting states have been experimentally observed on a same hydrophobic surface. For example, the wetting feature of water droplets on lotus leaves is the well-known superhydrophobicity with large contact angle (> 150°) and low rolling angle (< 5°) (typical Cassie–Baxter state). However, if a water droplet is formed by condensation in humid environments, a lotus leaf will become very sticky to the condensed water droplet (Wenzel state) [17], which destroys the superhydrophobicity of the material and strongly suppresses its water repellency. There have been intensive studies on wetting-mode transition through experiments, analyses, and numerical simulations. Due to the energy barrier between different wetting modes, external stimuli are usually adopted to achieve the wetting transition, such as applying pressure [16, 18–20], mechanical vibration [21], electric or magnetic field [22–24] and so on. It is found that not only the transition from the Cassie–Baxter to Wenzel state but also the Wenzel to Cassie–Baxter wetting transition can be achieved with external energy inputting. Zheng et al [19] obtained the critical hydraulic pressure that leads to the transition from Cassie–Baxter state to Wenzel one. Boreyko and Chen [21] studied the vibration-induced Wenzel to Cassie–Baxter wetting transition of a condensed water droplet on a lotus leaf. Koishi et al [25] numerically studied the effect of geometric parameters of surface texture on the wetting transition between Cassie–Baxter and Wenzel states.

Although reversible wetting transition can be achieved with the help of external stimuli, recently, a very interesting phenomenon of spontaneous wetting transition from Wenzel state to Cassie–Baxter one has been found experimentally [26–33]. Wang et al [34] found that condensed water can be self-removed from the legs of water striders owing to the elastic deformation of seta arrays by growing droplets. Boreyko and Chen [26] studied the self-propelled dropprise condensate on a micro-pillared superhydrophobic surface. It is found that condensed water droplets can spontaneously jump onto the top of the micro-pillar arrays due to the droplet coalescence. Lv et al [31] experimentally observed that spontaneous dewetting transition could occur either by an individual droplet growth or by the coalescence of two neighboring droplets. The coalescence induced movement of a condensed water droplet on a superhydrophobic surface has been systematically studied [31]. Mouterde et al [33] and Zhang et al [32] studied the effect of the shape of micro-structures on spontaneous dewetting transition. Although dewetting transition from the sticky Wenzel state to the non-sticky Cassie–Baxter one of condensed water droplets on natural or bio-inspired superhydrophobic surfaces has obtained significant achievements, the underlying transition mechanism is still unclear, especially lacking theoretical analysis. Furthermore, the effect of influencing factors on such a dewetting transition is also an open question.

To clarify the above questions, a two-dimensional (2D) thermodynamic model of a condensed water droplet in contact with a micro-pillar arrayed surface is established to study the dewetting transition from the Wenzel state to Cassie–Baxter one. Effects of micro-pillar’s shape, size and the volume of water droplet on the dewetting transition are considered. The abnormal phenomenon of a Wenzel wetting state of a condensed droplet on lotus leaves and the anti-fogging behavior of a mosquito’s compound eyes are further analyzed. The results could provide useful guidance for the biomimetic design of functional dewetting surfaces in real engineering.

2. Theoretical model of spontaneous dewetting transition

2.1. The general model with an arbitrary-shaped micro-pillar arrayed surface

A 2D theoretical model of a condensed water droplet in contact with a micro-pillar arrayed surface is established as shown in figure 1, in which the shape of the micro-pillar’s cross-section is arbitrary. \( H \) is the height of the micro-pillar, the base width of each pillar is \( 2a \) and the interval between neighboring micro-pillars is \( 2b \). Initially, when the volume of condensed water droplet is relatively small, the droplet with a spherical cap (\( \varphi \) is half of the central angle) is located at the bottom of two neighboring pillars (state I). A rectangular coordinate \( (x, z) \) is introduced

![Figure 1. Schematic of a 2D model of a water droplet condensed on a hydrophobic micro-pillar arrays with arbitrary cross-section shapes](image-url)
with the origin at the top of micro-pillar as shown in figure 1(a). The profile of the micro-pillar is denoted as \( z = z(x) \). When the droplet is located between the micro-pillars, the intrinsic contact angle \( \theta_f \) can be geometrically expressed by

\[
\cos \theta_f = \mathbf{m} \cdot \mathbf{n}
\]

(1)

where \( \mathbf{m} \) and \( \mathbf{n} \) denote the unit normal vectors of the solid–liquid and the liquid–air interfaces at the triple contact point \( (x = x_t) \), respectively. We have

\[
\mathbf{m} = \frac{-z'(x_t) \mathbf{i} + \mathbf{k}}{\sqrt{1 + [z'(x_t)]^2}}
\]

(2)

\[
\mathbf{n} = \frac{(a + b - x_t) \mathbf{i} + \sqrt{R_1^2 - (a + b - x_t)^2} \mathbf{k}}{R_1}
\]

(3)

Here, \( \mathbf{i} \) and \( \mathbf{k} \) are the unit vectors along \( x \) and \( z \) directions, respectively. Substituting equations (2) and (3) into (1) leads to the radius of liquid–air interface (see supplementary material for detailed derivations, available online at stacks.iop.org/JPhysCM/31/295001/mmedia)

\[
R_1 = \frac{(a + b - x_t) \sqrt{1 + [z'(x_t)]^2}}{-z'(x_t) \cos \theta_f + \sin \theta_f}.
\]

(4)

Therefore, the solid–liquid and the liquid–air interface areas in state I can be derived by

\[
A_{SLI} = 2b + 2 \int_{x_t}^{a} \sqrt{1 + [z'(x)]^2} \, dx
\]

(5)

\[
A_{LAI} = 2\varphi R_1
\]

(6)

and the volume of the condensed water droplet is the sum of the spherical cap and that below the cap,

\[
V = R_1^2 (\varphi - \sin \varphi \cos \varphi) + 2 \int_{z(x_t)}^{H} [a + b - x(z)] \, dz
\]

(7)

where \( x(z) \) is the inverse function of \( z(x) \).

When the volume of the water droplet increases to a critical value, spontaneous dewetting transition will occur (state II). The droplet at this state is assumed to be a spherical one, locating at the top of the micro-pillars as shown in figure 1(b). Due to the constant volume of the droplet at the moment of the dewetting transition, the radius \( R_{II} \) of the water drop in state II is

\[
R_{II} = \sqrt{\frac{V}{\pi}}
\]

(8)

and the liquid–air interface area is

\[
A_{LAI} = 2\pi R_{II}.
\]

(9)

The energy difference \( \Delta G \) between state I and state II can be obtained as,

\[
\Delta G = G_I - G_{II} = \gamma_{LA} A_{LAI} + \gamma_{SL} A_{SLI} + \gamma_{SA} A_{SAI} - \gamma_{LA} A_{LAI} - \gamma_{SA} A_{SAI}
\]

(10)

where the Young’s equation \([35]\) \( \gamma_{LA} \cos \theta_f = \gamma_{SL} - \gamma_{SA} \) and \( A_{SAI} - A_{SAI} = A_{SLI} \) are adopted.

Introducing the dimensionless parameters \( \tilde{a} = a/H \), \( \tilde{b} = b/H \), \( \tilde{x} = x/H \) and \( \tilde{z} = z(x)/H \), equations (7) and (10) can be rewritten as dimensionless forms

\[
\tilde{V} = \frac{V}{2(a + b) H} = R_1^2 (\varphi - \sin \varphi \cos \varphi) + 2 \int_{z(x_t)}^{H} [\tilde{a} + \tilde{b} - \tilde{x}(\tilde{z})] \, d\tilde{z}
\]

(11)

\[
\Delta \tilde{G} = \Delta G = 2(\varphi R_1 - \pi R_II) - 2 \cos \theta_f \left( \tilde{b} + \int_{z(x_t)}^{H} \sqrt{1 + \left[\tilde{z}'(\tilde{x})\right]^2} \, d\tilde{x} \right)
\]

(12)

where \( R_1 = (\tilde{a} + \tilde{b} - \tilde{a}_1) \sqrt{1 + \left[\tilde{z}'(\tilde{x})\right]^2} / [-\tilde{z}'(\tilde{a}_1) \cos \theta_f + \sin \theta_f] \) and \( R_{II} = \sqrt{2(a + b) V/\pi} \).

When \( \Delta \tilde{G} \) is larger than zero, state II is energetically stable due to the lower energy. Spontaneous dewetting transition from state I to state II would occur in this case. When \( \Delta \tilde{G} \) is smaller than zero, state I is more stable than state II, and the transition cannot happen.

Based on the above analysis, different kinds of micro-pillar arrays, including conical, rectangular and parabolic pillars, are considered as shown in figure 2.

2.2. Case I: the conical micro-pillar arrayed surface

Figure 2(a) shows the model of a water droplet condensed on a conical micro-pillar arrayed surface. \( \alpha \) is a half of the cone angle, and the profile of the cone can be expressed as \( \tilde{z} = \tilde{x}/\tan \alpha \).

(1) When the volume of water droplet is relatively small, the triple contact line lies on the side surface of conical pillars in state I as shown in figure 2(a). In this case, the volume of water droplet is

\[
V_{cone} = \frac{[(\cos(\alpha + \theta_f) + \sin(\alpha + \theta_f))] (\tan \alpha + \tilde{b} - \tilde{a}_1)^2}{2(\tan \alpha + \tilde{b})} + \frac{\tilde{z}_0(\cos(\alpha + \theta_f) + \sin(\alpha + \theta_f)) (\tan \alpha + \tilde{b})}{2(\tan \alpha + \tilde{b})}.
\]

(13)

If dewetting transition occurs in this case, the energy difference between state I and II can be obtained as

\[
\Delta \tilde{G}_{cone} = 2 \left[ (\alpha + \theta_f - \pi/2) \tilde{R}_1 - \pi \tilde{R}_II \right] - 2 \cos \theta_f \left( \frac{\tan \alpha - \tilde{b}_1 + \tilde{b}}{\sin \alpha} \right)
\]

(14)

where \( \tilde{R}_1 = (\tilde{a}_1 - \tan \alpha - \tilde{b}_1)/\cos(\alpha + \theta_f) \) and \( \tilde{R}_{II} = \sqrt{2(\tan \alpha + \tilde{b}) V_{cone}/\pi} \).

(2) When the volume of condensed water droplet increases, the triple contact line will be pinned at the top of conical pillars. In this case, the droplet volume can be rewritten as

\[
V_{cone} = \frac{(\varphi - \sin \varphi \cos \varphi)}{2} \left( \frac{\tan \alpha + \tilde{b}}{\sin \alpha} \right) + \frac{\tan \alpha + \tilde{b} \varphi}{2(\tan \alpha + \tilde{b})}.
\]

(15)

If dewetting transition occurs in this case, the energy difference between state I and II is
and the energy difference before and after dewetting transition in this case can be expressed as
\[
\Delta G_{\text{rect}} = 2 \left[ (\theta_y - \pi / 2) R_{\text{I}} - \pi R_{\text{II}} \right] - 2 \cos \theta_y \left( \bar{b} + 1 - \bar{z}_t \right)
\]
where \( R_{\text{I}} = -b / \cos \theta_y \) and \( R_{\text{II}} = \sqrt{2bV_{\text{rect}} / \pi} \). (18)

(2) For the case of triple contact line pinned at the top of pillar, the volume of the water droplet and the energy difference can be respectively obtained as,
\[
V_{\text{rect}} = \frac{(\varphi - \sin \varphi \cos \varphi)}{\sin^2 \varphi} \cdot \frac{\bar{b}}{2} + 1 \quad (19)
\]
\[
\Delta G_{\text{rect}} = 2 \frac{\varphi}{\sin \varphi} \bar{b} - 2 \sqrt{\pi} \left[ \frac{(\varphi - \sin \varphi \cos \varphi) \bar{b}^2 + 2\bar{b}}{\sin^2 \varphi} \right] - 2 \cos \theta_y \left( 1 + \bar{b} \right) \quad (20)
\]

2.4. Case III: the parabolic micro-pillar arrayed surface

It is well known that the specially superhydrophobic wettability of many natural materials, such as lotus leaves and mosquito compound eyes, is mainly due to the surface roughness [12, 36] which is similar to parabolic pillar-like surface with micro-/nano-scale. Here, a model of a condensed water droplet in contact with a parabolic micro-pillar arrayed surface is further considered as shown in figure 2(c). The profile of the parabolic-shaped micro-pillar is \( z = k^2 x^2 \) \((k = 1/\bar{a})\). The volume of water droplet and the energy difference can be respectively expressed by
\[
V_{\text{para}} = \frac{\bar{R}_{\text{I}}^2 (\varphi - \sin \varphi \cos \varphi)}{2 (k^{1-b})} + 1 - k^2 x_i^2 \frac{2}{3} \left( -k^{-1} + \frac{k^2 x_i^3}{k^{-1} + b} \right) \quad (21)
\]
\[
\Delta G_{\text{para}} = 2 (\varphi R_I - \pi R_{\text{II}}) - 2 \cos \theta_y \left( \bar{b} + \int_{x_i}^{x_{\text{I}}} \sqrt{1 + 4k^4 x^2} \, dx \right) \quad (22)
\]
where \( R_{\text{I}} = (k^{-1} + 1 - x_i) \sqrt{1 + 4k^4 x^2} / (-2 \cos \theta_y k^2 x_i + \sin \theta_y) \), \( R_{\text{II}} = \sqrt{2 (k^{-1} + b)} V_{\text{para}} / \pi \) and \( \varphi = \arccos \left( \sqrt{\frac{\bar{R}_{\text{I}}^2}{k^{-1} + \bar{b} - x_i^2} / R_{\text{I}}} \right) \).

One should note that, for the case of parabolic micro-pillar arrays, as the volume of water droplet increases, the triple contact line moves along the side surface of the pillar. When the triple contact line reaches the top of pillar, it cannot be pinned due to the smooth profile of the pillar, which is different from cases of conical and rectangular pillars. If the free energy in state I at the moment of the triple contact line reaching the top of pillar is still smaller than state II, dewetting transition from state I to state II cannot be achieved for parabolic pillars, which leads to a maximum water droplet volume,
\[
V_{\text{max para}} = \frac{(k^{-1} + \bar{b}) (\theta_y - \sin \theta_y \cos \theta_y)}{2 \sin^2 \theta_y} + 1 - \frac{2}{3} \frac{1}{k^{-1} + b} \left( -k^{-1} + \frac{k^2 x_i^3}{k^{-1} + b} \right) \quad (23)
\]
3. Results and discussion

The energy difference $\Delta G_{\text{cone}}$ for conical micro-pillar arrayed surface as a function of the volume of condensed water droplet $V_{\text{cone}}$ is shown in figures 3(a)–(c), in which the effect of cone angle $\alpha$, the pillars interval $b$ and the intrinsic contact angle $\theta_f$ is indicated, respectively. It is shown that when the volume of water droplet is relatively small, the energy difference $\Delta G_{\text{cone}}$ is smaller than zero, resulting in the more stable state I as shown in figure 2(a) than state II. When the water volume increases to be larger than a critical value, the energy difference $\Delta G_{\text{cone}}$ becomes positive. In this case, spontaneous dewetting transition from state I to state II would occur because state II is more energetically stable than state I. From figures 3(a)–(c), one can see that the critical water volume $V_{\text{cr}}$ increases with the increase of the cone angle $\alpha$ and pillar’s interval $b$, while decreases with the increase of the intrinsic contact angle $\theta_f$ with other parameters determined. Similar tendency of energy difference $\Delta G_{\text{rect}}$ with the volume of water droplet $V_{\text{rect}}$ can be found for the case of rectangular micro-pillar arrays as shown in figure 4. It is shown that a critical water volume $V_{\text{cr}}$ exists, beyond which the energy difference $\Delta G_{\text{rect}}$ is larger than zero, leading to spontaneous transition from state I to state II as shown in figure 2(b). The critical water volume $V_{\text{cr}}$ increases with an increasing pillar’s interval $b$ and a decreasing intrinsic contact angle $\theta_f$ when the other parameters are fixed as shown in figures 4(a) and (b).

In figures 3 and 4, each circle symbol denotes the moment that the triple contact line is pinned at the top of pillars. From figures 3 and 4, one can see that the energy difference $\Delta G$ at the moment of the triple contact line pinned at the top of pillar is always negative and the spontaneous dewetting transition usually occurs after the triple contact line is pinned at the top of pillars. That is to say dewetting transition from state I to state II cannot be achieved before the triple contact line is pinned at the top of pillars. Such a theoretical result is well consistent with the existing experimental and numerical works [31, 32]. Lv et al [31] experimentally studied the dewetting transition of dropwise condensation on a nano-textured superhydrophobic surface, and they found that one mode of spontaneous dewetting transition is the growth of an individual droplet: when the volume of droplet continues to increase after it is pinned at the top of pillars, dewetting transition happens suddenly [31]. Zhang et al [32] numerically studied the dewetting transition of a condensed water droplet on conical and cylindrical pillar arrayed surfaces with the help of lattice Boltzmann simulations, and also found that spontaneous dewetting transition occurs after the droplet is pinned at the top of pillars.

Figure 5 gives the energy difference $\Delta G_{\text{para}}$ of the parabolic pillar arrays as a function of water volume $V_{\text{para}}$ with different pillars interval $b$ and intrinsic contact angle $\theta_f$. From figure 5(a), it is found that the energy difference $\Delta G_{\text{para}}$ gradually increases from a negative value to a positive one with the increase of the water volume $V_{\text{para}}$ when the pillar’s interval $b$ is relatively small ($b = 0.02$) with other fixed parameters $k = 5$ and $\theta_f = 120^\circ$. In this case, dewetting transition from state I to state II can occur when the water volume increases to be a critical one. However, when the pillars interval $b$ is relatively large, i.e. $b = 0.05$, and 0.1 as shown in figure 5(a), the energy difference is always smaller than zero with the water
volume increasing to the maximum derived by equation (23).
In this case, state I as shown in figure 2(c) is always the energetically favorite state. Similar wetting phenomenon can also be found for the effect of intrinsic contact angle as shown in figure 5(b), in which one can see that dewetting transition can only occur when the intrinsic contact angle is relatively large ($\theta_Y = 120^\circ$) with $\bar{k} = 5$ and $\bar{b} = 0.02$. For the cases of relatively small contact angles, i.e. $\theta_Y = 100^\circ$ and $110^\circ$, dewetting transition cannot be achieved due to the negative energy difference as shown in figure 5(b).

Some interesting experimental observations may be explained by the present model, such as the abnormal Wenzel wetting state of the surface of lotus leaves and the antifogging behavior of mosquito’s compound eyes, both of which have similar shape of microstructures but with different pillar sizes and intervals. It is well known that the surface of lotus leaves shows a super-hydrophobicity feature with a contact angle greater than $150^\circ$ and the droplet is easy to roll down with a rolling angle less than $5^\circ$ if a droplet is directly placed on it. However, in Cheng and Rodak’s experiment [17], they found that a droplet formed by condensation would adhere to the surface of lotus leaves and do not roll off, even if the surface is tilted $90^\circ$. It can be inferred that the droplets directly placed on the surface of lotus leaves are in a Cassie–Baxter state, while the droplets formed by condensation are in a Wenzel state and cannot realize state transfer spontaneously. As for the case of compound eyes, it is found experimentally that the mosquito’s compound eyes remain anti-fogging even in a heavily foggy environment [11, 12]. It can be inferred that droplets on compound eyes formed by condensation can easily make a Wenzel to Cassie–Baxter state transition and roll off. In order to explain the two interesting phenomena, the bump-like roughness on lotus leaves and mosquito compound eyes is modeled as parabolic micro-pillar arrays with different real sizes. Substituting the parameters $\bar{k} = 2$, $\bar{b} = 0.5$ ($a = 5 \mu m$, $b = 5 \mu m$, $H = 10 \mu m$), $\theta_Y = 140^\circ$ [36, 37] for lotus leaves and $\bar{k} = 1$, $\bar{b} = 1/13$ ($a = 13 \mu m$, $b = 1 \mu m$, $H = 13 \mu m$), $\theta_Y = 145^\circ$ [12] for mosquito compound eyes into equation (22) results in the energy difference as a function of the condensed water volume as shown in figure 6. It is...
found that the energy difference is always negative for lotus leaves, which means that the Wenzel state of a condensed water droplet on lotus leaves is stable, and cannot transit to the Cassie–Baxter state spontaneously. For mosquito’s eyes, the energy difference becomes positive at a small water volume, which indicates that the spontaneous wetting transition from a Wenzel state to a Cassie–Baxter one can be easily achieved at a small critical water volume on mosquito’s eyes. The results shown in figure 6 may provide possible explanations for the abnormal Wenzel wetting state of condensed water droplets on lotus leaves and the anti-fogging behavior of mosquito’s compound eyes. Of course, wetting transition from a Cassie–Baxter state to a Wenzel state or from a Wenzel state to a Cassie–Baxter state on lotus leaves can be further realized by external stimuli, such as applying pressure [19] and mechanical vibration [21].

The critical droplet volume $V_{cr}$ at which the dewetting transition occurs varying with the intrinsic contact angle $\theta_f$ for the conical, rectangular and parabolic micro-pillar arrays is shown in figure 7 with $a = 0.2$ ($\alpha = 11.31^\circ$) and $b = 0.1$. It is shown that when the contact angle is relatively small (i.e. $\theta_f < 126^\circ$), dewetting transition occurs for conical and rectangular pillars, but cannot occur for parabolic pillars because the energy difference is always negative with the droplet volume increasing to the maximum as expressed in equation (23). Furthermore, the critical volume for rectangular pillars is smaller than that of conical ones at a given contact angle and geometrical size, which means the dewetting transition is easier for rectangular pillars than conical ones in cases with relatively small contact angles. When the contact angle is relatively large (i.e. $\theta_f > 126^\circ$), dewetting transition can occur for all three pillared surfaces, among which the critical droplet volume for parabolic pillars is the smallest. It means that the parabolic pillars should have the best dewetting transition property in case of relatively large contact angles. Such a result may be explained by the pinning effect. It shows that spontaneous dewetting transition for rectangular pillar arrays would occur only when the triple contact line is pinned at the top of pillars, which is consistent with the experimental observation [31] and numerical simulation [32]. However, there is no pinning process for the triple contact line on the parabolic pillar arrays due to the smooth surface. In addition, only when the condensed droplet fully fills the rectangular pillar gap due to the pinning effect, would the dewetting transition occur. While for the parabolic pillar case, dewetting transition may occur when the triple contact line moves to a certain position on the side surface of the pillar, at which time the droplet may not necessarily fully fill the parabolic pillar gap.

4. Conclusions

A 2D thermodynamic model of a condensed water droplet on a hydrophobic micro-pillar arrayed surface is established to find the mechanical mechanism underlying the dewetting transition observed in recent experiments. Three types of micro-structures, including conical, rectangular and parabolic pillars, are considered. The energy difference before and after dewetting transition is obtained analytically for differently shaped micro-pillar arrays. A critical volume of water droplets is found, beyond which the dewetting transition can be achieved. It is shown that the smaller the pillar’s interval or the larger the intrinsic contact angle, the easier the dewetting transition may happen. For the case of parabolic micro-pillars, dewetting transition may not be achieved in the case with relatively large pillar’s interval or relatively small contact angle because the triple contact line cannot be pinned at the top of parabolic pillars. Possible explanations for the abnormal Wenzel wetting state of condensed water droplets on lotus leaves and the anti-fogging behavior of mosquito’s compound eyes are further given. The obtained results should be very helpful for the biomimetic design of functional wetting surfaces in real applications, such as self-cleaning, anti-fogging and water-repellent surfaces.
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