Supporting information

Towards understanding whether superhydrophobic surfaces can really decrease fluidic friction drag

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1. Characterization of a superhydrophobic ball

The wetting performance of a flat superhydrophobically modified surface was also detected and shown in Figure S1(a´´–d´´). The surface so greatly repelled water that a 4-µL water droplet began to roll off at a quite low sliding angle (< 1°). Advancing and receding contact angles were measured by increasing or decreasing the volume of the water drops sitting on the surfaces and the values were 168° and 157°, respectively.
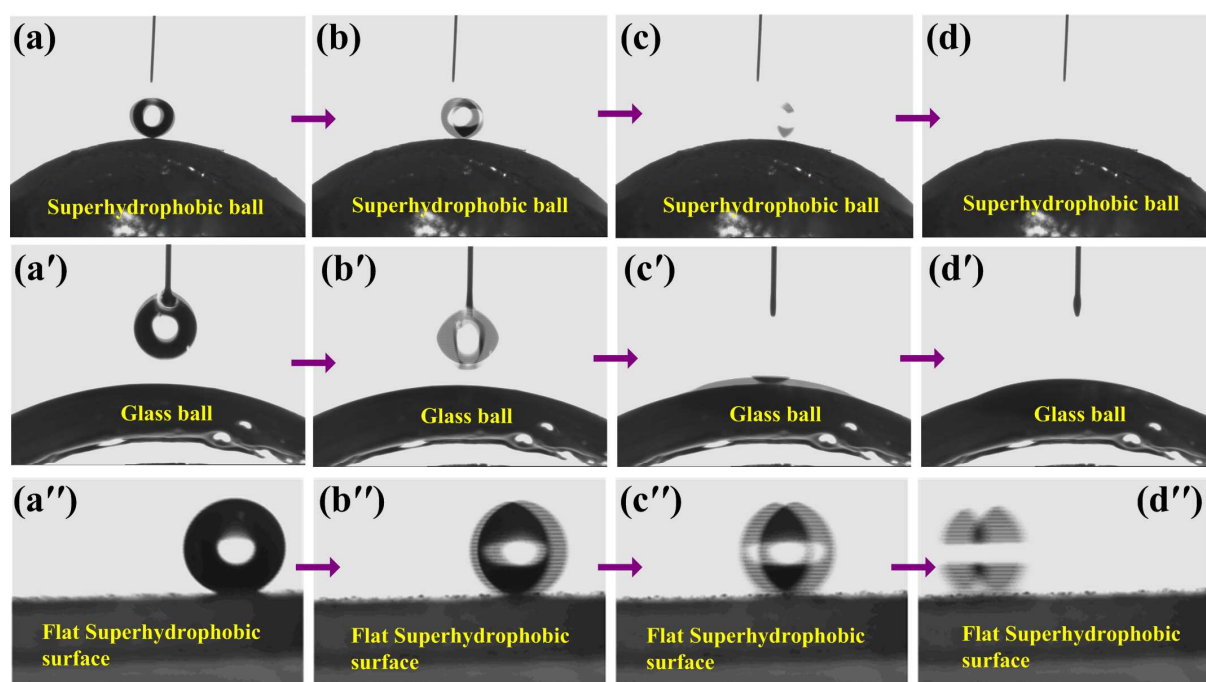

Figure S1. A 4-µL water drop (a–d) rolling off a superhydrophobically modified ball and (a´–d´) spreading on a pre-cleaned normal glass ball. (a´´–d´´) a 4-µL water drop sliding off a flat superhydrophobic surface, the sliding angle is lower than 1°.

Figure S2(f) shows the energy dispersive spectroscopy (EDS) spectrum of the superhydrophobic surface. Three major peaks at 0.28, 0.56 and 1.78 keV in the EDS spectra can ascribe to carbon, oxygen and silicon elements and their molar percentage was 58.85%, 30.51% and 10.64%, respectively. Silicon element came from hydrophobic silica particles and carbon, oxygen elements were partly contributed by PET.

The composite surface was also investigated by reflected FT-IR spectroscopy and the result is shown in Figure S2(g). Typical silica bands, most notably the silanol stretching vibration at 3430 cm^{-1} and asymmetric Si-O-Si stretching vibration at 1000-1200 cm^{-1} can be assigned to hydrophobic silica particles. The absorption bands of PET including C-H and C=O stretching vibration appear at 2967cm^{-1} and 1648cm^{-1}, respectively. The absorption band of CH$_3$ rocking vibration at 803 cm^{-1} can attribute to poly-(dimethylsiloxane) (PDMS) modified on silica particles.
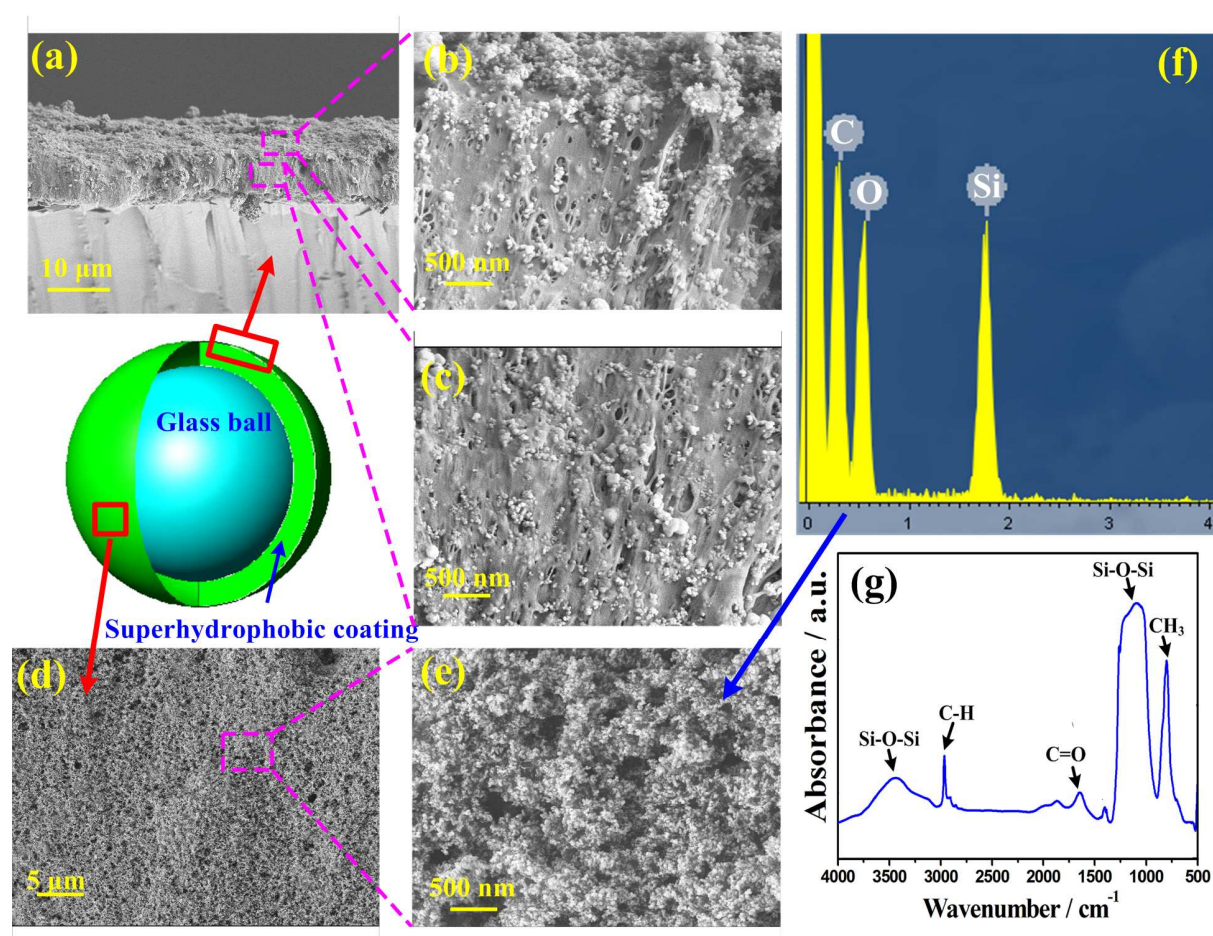

Figure S2. (a) Cross-sectional and (d) top-view SEM images of the superhydrophobic coatings on a glass ball, showing many of the hydrophobic silica nanoparticles distributed at the outside layer of the coatings. (b), (c) and (e) are magnified images of (a) and (d), respectively. (f) Corresponding EDS spectrum and (g) reflected FT-IR spectrum of the superhydrophobic composite coating.

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2. Movement of a superhydrophobic ball and a pre-cleaned glass ball of the same mass and diameter on a water surface

Table. S1 Diameter and mass of the normal glass ball and the superhydrophobic ball

	Normal glass ball	Superhydrophobic ball
Diameter in X axis(cm)	1.882	1.890
Diameter in Y axis(cm)	1.885	1.878
Diameter in Z axis(cm)	1.880	1.887
Average diameter (cm)	1.882±0.002	1.885±0.006
Mass (g)	1.8181	1.8060

In this test, we fixed two metallic L-shaped channels of the same size on top of the trough. Before the experiment, the superhydrophobic ball and the normal glass ball were carefully held separately on the top of each channel by a solid plate. As soon as the plate was withdrawn, the two balls fell down along the channels simultaneously and then moved horizontally on the water surface. The gravitational potential energy of two balls at the same height was transferred into the same kinetic energy (it was assumed that the channels were ideally smooth so that frictional force can be neglected) and the balls would have the same speed at the beginning of their horizontal movement:

$$m_b gh = \frac{1}{2} m_b v^2,$$

(1)

where m_b, g, h, and v are the mass of the ball, acceleration due to gravity, initial height and ball speed at the end of the channel, respectively. Thus, the speed v is determined only by the initial height and is independent of the mass. During subsequent horizontal movement, possible diversity caused by the mass difference ($\Delta m = 0.0121$ g) between the two balls can be neglected because the speed is only influenced by friction drag horizontally and their weight is totally supported by their buoyancy in the vertical direction. Therefore, the original position data were used without correction.
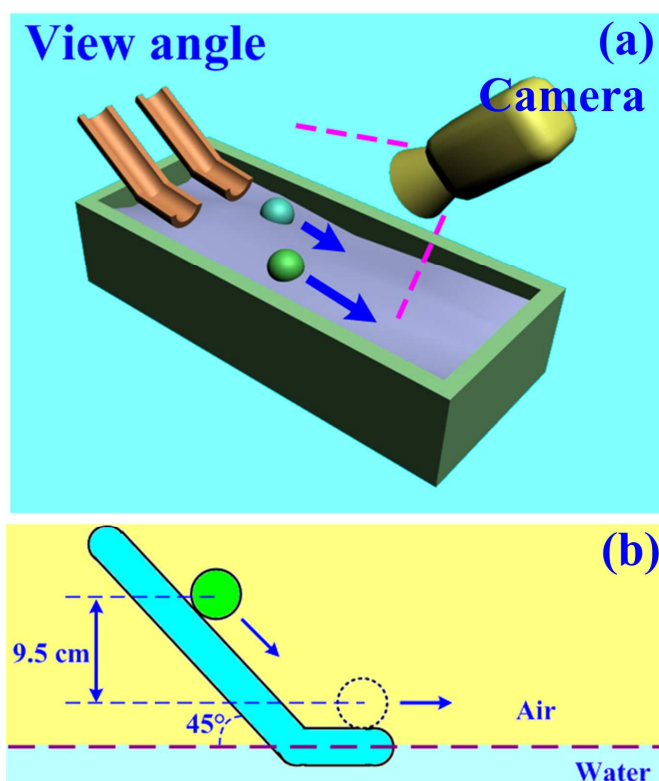
Figure S3. (a) Viewing angle of the digital camera used to observe movement of a superhydrophobic ball and a normal glass ball on the water surface. (b) Schematic illustration of the experimental set-up.

3. Underwater movement of a superhydrophobic ball and a normal glass ball of the same mass and diameter

3.1 Vertical falling behavior

Table S2. Diameter and mass of the normal glass ball and the superhydrophobic ball

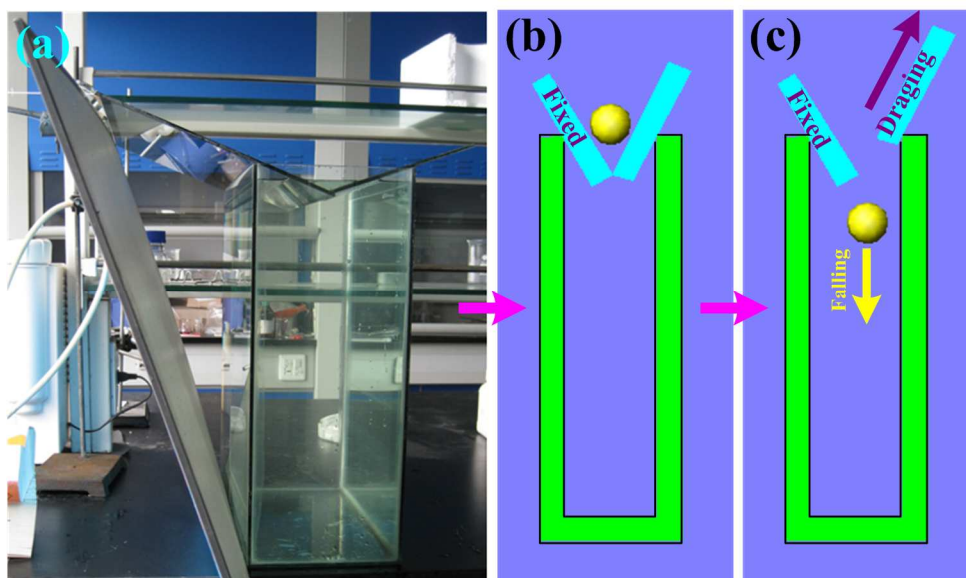|	Normal glass ball	Superhydrophobic ball
Diameter on the x-axis (cm)	1.902	1.894
Diameter on the y-axis (cm)	1.892	1.908
Diameter on the z-axis (cm)	1.912	1.886
Average diameter (cm)	1.902±0.010	1.896±0.011
Mass (g)	5.5881	5.5526

Figure S4. (a) Side view of the trough used to observe vertical falling of a superhydrophobic ball and a normal glass ball under water. (b,c) Schematic diagram of the process for releasing the two balls at the same height by withdrawing one of the glass plates.

3.2 Horizontal movement underwater

The process for movement of the two balls under water was similar to that for movement above the water surface but a pair of heavier balls was used (the diameter and weight of the balls are shown in Table S2). A glass sheet was fixed at the end of the two L-shaped channels so the balls would move horizontally under water after running down along the channels. During subsequent horizontal movement, possible diversity caused by the mass difference ($\Delta m = 0.0355$ g) between the balls can be neglected because the speed is only influenced by friction drag horizontally and their weight is totally supported by the substrate in the vertical direction. Therefore, the original position data were used without correction. The two balls started under water and at a height of 12.1 cm the superhydrophobic ball moved more slowly on the glass sheet. The average rate in 1.2 s was 9.0 and 10.3 cm s^{-1} for the superhydrophobic and glass balls, respectively
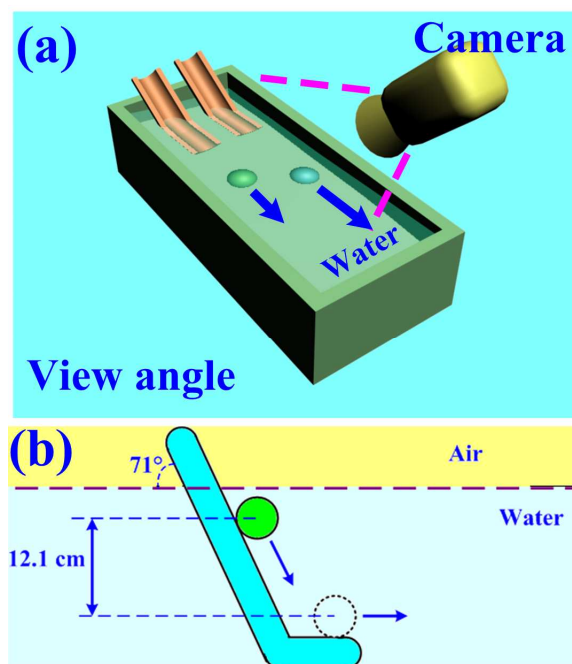
Figure S5. (a) Viewing angle of the digital camera used to observe the movement of a superhydrophobic and normal glass ball below the water surface. (b) Schematic illustration of the experimental set-up.

4. Characterization of nanobubbles trapped in the superhydrophobic surface

4.1 Observation of nanobubbles trapped in the superhydrophobic surface using an underwater microscope
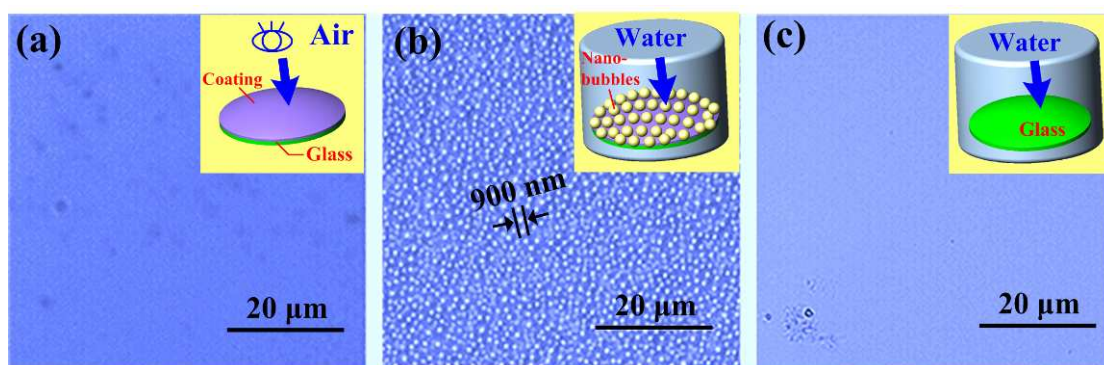

Figure S6. (a) Microscopy image of the superhydrophobic surface in air. (b) Underwater microscopy image of the superhydrophobic surface showing numerous trapped nanobubbles. (c) Underwater microscopy image of a clean glass surface showing no trapped nanobubbles.

4.2 Thickness of nanobubble layer surrounding the superhydrophobic ball and the corresponding increased surface area

To calculate the thickness of nanobubble layer surrounding the superhydrophobic ball, we used the Archimedes principle, which states that the mass of water displaced by an object is proportional to the volume of the object. A 50-mL weighing bottle was placed in a dried beaker and fully filled with water. A normal glass ball or superhydrophobic ball was carefully dropped into the bottle and water overflowed from the weighing bottle into the beaker underneath owing to displacement by the ball. The mass of water in the beaker was weighed and the volume of the ball was calculated. In our experiment, the mass of water displaced by the normal glass ball, Δm_1, was 2.3084 g. In contrast, the mass of water displaced by the superhydrophobic ball, Δm_2, was 2.3580 g. In fact, the mass of water displaced by the glass ball or superhydrophobic ball was less than that calculated from the measured diameters shown in Table. S2. This discrepancy in mass between measured and calculated values was attributed to the shape shift of the water surface on the top of the weighing bottle. The water surface was kept horizontal to the edge of the bottle hole before the balls were dropped in and then transformed to a deformed convex meniscus because of surface tension after that water overflowed. As a result, measured values are smaller than the theoretical ones. However, this difference does not affect measurement of the air layer because only the difference in displaced water caused by the two balls ($\Delta m_2 - \Delta m_1$) is involved.

Since there were no air bubbles attached to the normal glass ball (Fig. S5c), the mass of displaced water reflects the real volume of the bare ball itself, whereas the mass of water displaced by the superhydrophobic ball relates to the volume of the ball and the surrounding nanobubble layer (Fig. S5b).

Therefore, the volume of the nanobubble layer can be calculated as:

$$\Delta V = \frac{\Delta m_2 - \Delta m_1}{\rho} = \frac{(2.3580 - 2.3084)\,\mathrm{g}}{1.0\,\mathrm{g\,cm^{-3}}} = 0.0496\,\mathrm{cm^3} \tag{2}$$

where ρ is the density of water at room temperature.

Because the diameter of the normal glass ball (d_1) was greater than that of superhydrophobic ball (d_2), we should also consider the discrepant volume $\Delta V_{corrected}$, which can be calculated as:

$$\Delta V_{corrected} = \frac{\pi}{6}d_1^{\;3} - \frac{\pi}{6}d_2^{\;3} = \frac{3.14}{6}\left((1.902\,\mathrm{cm})^3 - (1.896\,\mathrm{cm})^3\right) = 0.0340\,\mathrm{cm^3} \tag{3}$$

Consequently, the corrected volume of the nanobubble layer is:

$$\Delta V^{'} = \Delta V + \Delta V_{corrected} = 0.0496\,\mathrm{cm^3} + 0.0340\,\mathrm{cm^3} = 0.0836\,\mathrm{cm^3} \tag{4}$$

The thickness of the nanobubble layer on the superhydrophobic ball is approximately:

$$d = \frac{\Delta V^{'}}{\pi d_2^{\;2}} = \frac{0.0836\,\mathrm{cm^3}}{3.14 \times (1.896\,\mathrm{cm})^2} = 0.00740\,\mathrm{cm} = 74.0\,\mathrm{\mu m} \tag{5}$$

The increase in surface area generated by the nanobubble layer on the superhydrophobic ball compared to the original surface area can be calculated as:

$$\frac{\Delta S}{S} = \frac{\pi(d_2 + 2d)^2 - \pi d_2^{\;2}}{\pi d_2^{\;2}} = \frac{3.14 \times (1.896\,\mathrm{cm} + 2 \times 0.00740\,\mathrm{cm})^2 - 3.14 \times (1.896\,\mathrm{cm})^2}{3.14 \times (1.896\,\mathrm{cm})^2} = 0.0157 \tag{6}$$

The increase in surface area caused by the nanobubble layer is quite small. It should be noted that the actual thickness of the nanobubble layer might be smaller than the calculated results. Accordingly, this is ignored in the discussion.
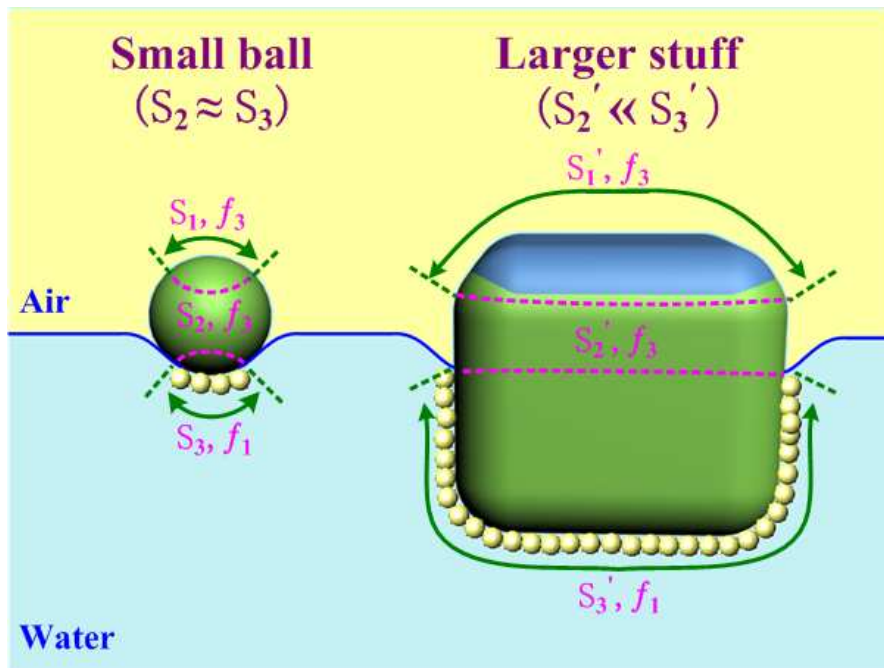
Figure S7. Comparison of a small superhydrophobical ball
and a huge boat floating on the water surface