

Electronic Supplementary Information

Integrative Bioinspired Venation Network with Ultra-Contrasting Wettability for Large-Scale Strongly Self-Driven and Efficient Water Collection

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Supplementary text

Calculation of Laplace pressure

The water in superhydrophilic channels is restricted by the margin of superhydrophilic area, so the width of water (in channel) profile ($\beta < 90^\circ$) is constant and equals to the width of the channel (w). Assuming that the water profile (on channels) is a cylindrical cap shape, R and β can be related as:

$$R = \frac{w}{2\sin\beta} \quad (1)$$

Where R is the radius of the corresponding cylindrical cap, β is the water-spreading-cross-section-angle (WSCSA).

The Laplace pressure ΔP in channels can be calculated from Young-Laplace Equation:

$$\Delta P = 2\gamma H = 2\gamma\left(\frac{1}{2R_1} + \frac{1}{2R_2}\right) = \frac{\gamma}{R} = \frac{2\gamma\sin\beta}{w} \quad (2)$$

where γ is the surface tension of water, H is the mean curvature, R_1 and R_2 are principal radii of curvature (for cylindrical shape, $R_1=R$, $R_2=\infty$).

The Laplace pressure ΔP in water reservoir is:

$$\Delta P = 2\gamma H = 2\gamma\left(\frac{1}{2R_1} + \frac{1}{2R_2}\right) = \frac{2\gamma}{R} = \frac{4\gamma\sin\beta}{w} \quad (3)$$

For spherical shape, $R_1=R_2=R$.

Calculation of balanced pressure: There are two kinds of pressure in the channel network during the water collecting process: the balanced pressure P_b and the local instantaneous

pressure P_{ins} . When there is water in the channel network, the water spreads into the entire network and the water pressure reaches a balanced pressure P_b . Whenever the droplets are sucked by the channels, there appears a local instantaneous pressure P_{ins} at sucking positions.

In the network, all the channels are connected, and the water can flow freely in the entire channel network. When no drop coalesces into the channels, the water reaches a static balance. Due to the surface tension, the surface of the water on channels is like a layer of thin film, which wraps and restricts the water. In this case, the surfaces of water and the channels nearly compose a closed container, the water in the closed container is similar to the confined incompressible fluid. The relationship of the pressure on channels at two points can be described by Pascal' principle:

$$P(x_1, y_1, z_1, t) - P(x_2, y_2, z_2, t) = \rho g z_2 - \rho g z_1 \quad (4)$$

here $P(x, y, z, t)$ represents the pressure in the water on channel network at the location (x, y, z) and at time t . x and y are horizontal coordinates while z is vertical coordinate.

The channel network is horizontal ($z_1 - z_2 = 0$) and the profile height of the water on channels can be ignored ($z_1 = z_2 \approx 0$). Therefore the right-hand side of the equation (4) is approximately zero. A simplified relationship can be:

$$P(x_1, y_1, t) = P(x_2, y_2, t) \quad (5)$$

And then, the following relationship can be obtained:

$$P(x_1, y_1, t) = P(x_2, y_2, t) = \dots = P(x_n, y_n, t) = P_b(t) \quad (6)$$

where $P_b(t)$ is the balanced pressure at time t . The pressure inside the water spreading on channels can be calculated from this following equation:

$$P(x, y, t) = P_0 + \Delta P(x, y, t) \quad (7)$$

where P_0 is the atmospheric pressure and $\Delta P(x, y, t)$ is the Laplace pressure at location (x, y) and time t .

And then, further relationship can be get:

$$\Delta P(x_1, y_1, t) = \Delta P(x_2, y_2, t) = \dots = \Delta P(x_n, y_n, t) = \Delta P_b(t) \quad (8)$$

This means that ΔP is the function of time t and has no relationship with the location (x, y) . In other words, ΔP is uniform at any location in the entire channel network system at a certain moment.

Therefore, β_b at any position in channels at any time can be calculated by the following relationship:

$$\beta_b(w, t) = \arcsin\left(\frac{\Delta P_b(t) \times w}{2\gamma}\right) \quad (9)$$

and β_b in water reservoir at any time by the following relationship:

$$\beta_b(w, t) = \arcsin\left(\frac{\Delta P_b(t) \times w}{4\gamma}\right) \quad (10)$$

Two conclusion can be summarized through the calculation of balanced pressure P_b :

- a. The balanced pressure P_b is uniform at any position on the entire channel network system at a certain moment and so is the balanced Laplace pressure ΔP_b .
- b. The WSCSA β_b is the function of t and w . At a certain moment, β_b is positively associated with w . In other words, the β_b in wider channels is larger than that in narrower one at the same moment. This indicates that the narrower channels hold much less water compared to wider channels, and the circle reservoir receives the most available water eventually.

Calculation of instantaneous pressure

When the water spreads into the entire network and reaches a balanced state, the water on channels is similar to the confined incompressible fluid. However, the container comprised of the water surface and channels is not truly closed container. The water in this container is not true confined incompressible fluid. Once some droplets are sucked into the water on channels, the balance of corresponding location is disturbed and the volume of water in this position increases dramatically in a very short time. There is a local instantaneous Laplace pressure ΔP_{ins} :

$$\Delta P_{ins}(w, t) = \frac{2\gamma \sin \beta_{ins}(w, t)}{w} \quad (11)$$

The increase of the volume of water in local position leads to:

$$\beta_{ins}(w, t) > \beta_b(w, t) \quad (12)$$

And

$$\Delta P_{ins}(x, y, t) > \Delta P(x, y, t) = \Delta P_b(t) \quad (13)$$

For example, when water sucking happens in the 4th channel with width of 70 m, ΔP_{ins} increases from 40Pa to 2000Pa as β_{ins} increases from 1.1 ° to 90 °. Such a huge pressure difference ($\Delta P_{ins} - \Delta P_b$) provides an enormous driving force to push the just-sucked water immediately to the other areas in the channel network until β_{ins} return to the value equal to $\beta_b = 1.1$ °.

Supplementary Figures

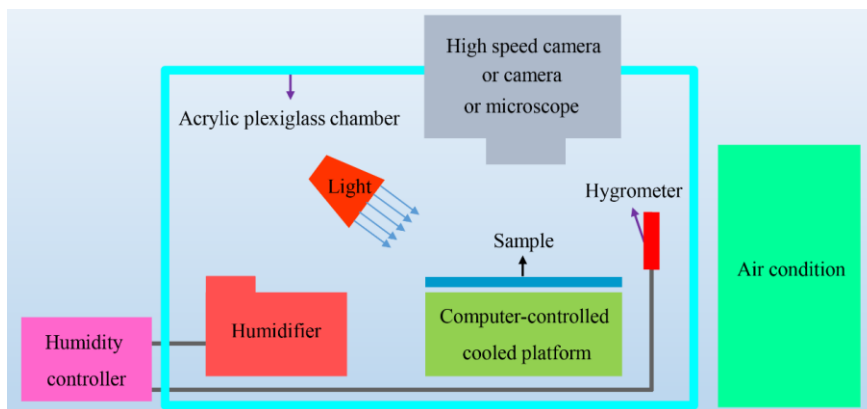


Figure S1. Condensation experiment platform.

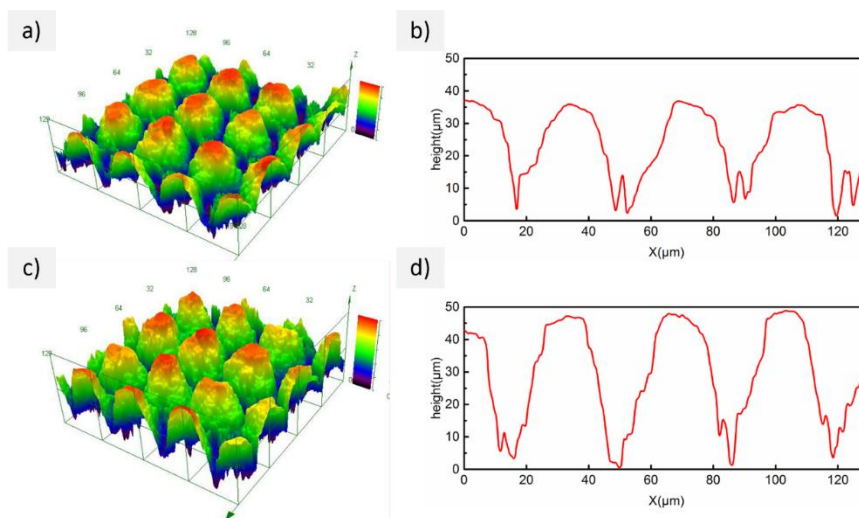


Figure S2. 3D laser microscope images of micro-nano structure on aluminum. (a) Surface 3D height map of micro-nano structure by first laser irradiation. b) The profiles of micro-nano structure by first laser irradiation. c) Surface 3D height map of micro-nano structure by second laser irradiation. d) The profiles of micro-nano structure by second laser irradiation.

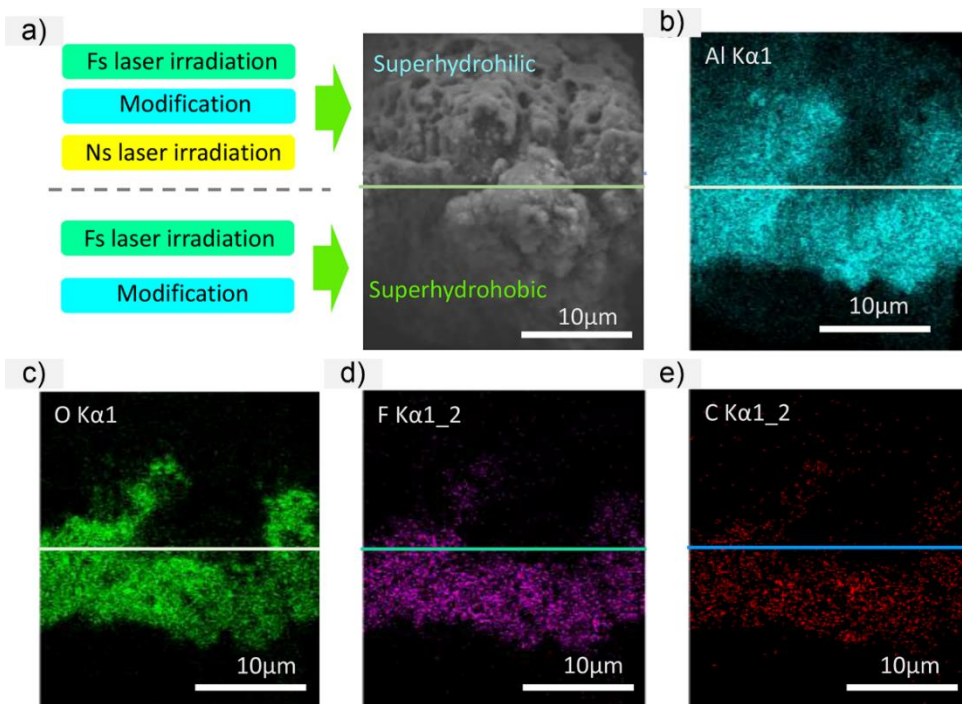


Figure S3. The composition comparison (EDS) before and after the second laser irradiation. a) High magnification SEM images for micro-nano structure. The upper portion is micro-nano structure after second laser irradiation and the lower portion is micro-nano structure before second laser irradiation. b-e) Elemental mapping of Al K α 1, O K α 1, F K α 1_2 and C K α 1_2 contained in these two structures. There are more F, C and O in micro-nano structure before the second laser irradiation than micro-nano structure after second laser irradiation. This demonstrates that the 1H, 1H, 2H, 2H-perfluorodecyltrimethoxysilane modified layer was removed from the surfaces after the second laser irradiation.

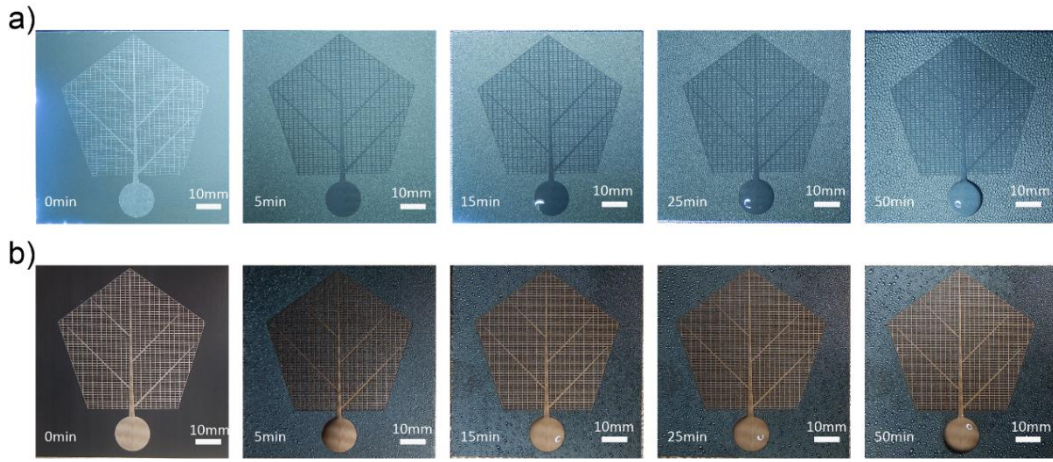


Figure S4. Time-lapsed optical images of water collection process of the leaf-vein-like networks which are fabricated on different materials. a) SiO₂ wafers. b) Copper.

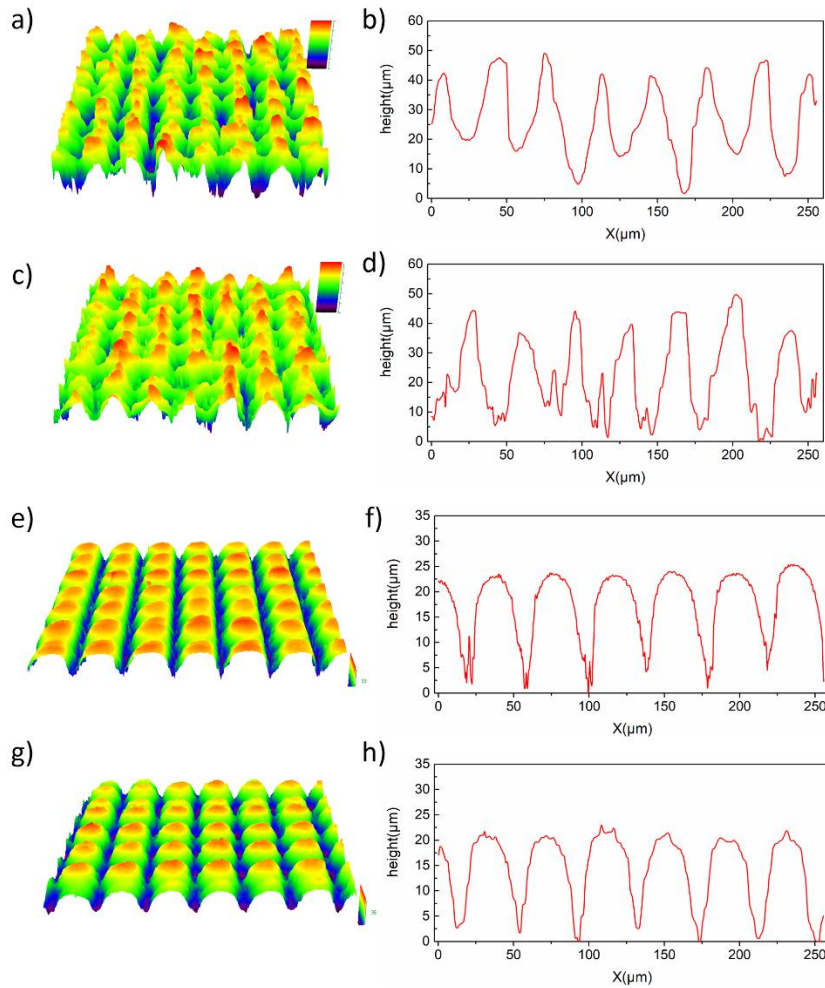


Figure S5. a), e) Surface 3D height map of micro-nano structure of SiO₂ wafers (a) and copper (e) by the first laser irradiation. b), f) The profiles of micro-nano structure of SiO₂ wafers (b) and copper (f) by first laser irradiation. c), g) Surface 3D height map of micro-nano structure of SiO₂ wafers (c) and copper (g) by second laser irradiation. d), h) The profiles of micro-nano structure of SiO₂ wafers (d) and copper (h) by second laser irradiation.

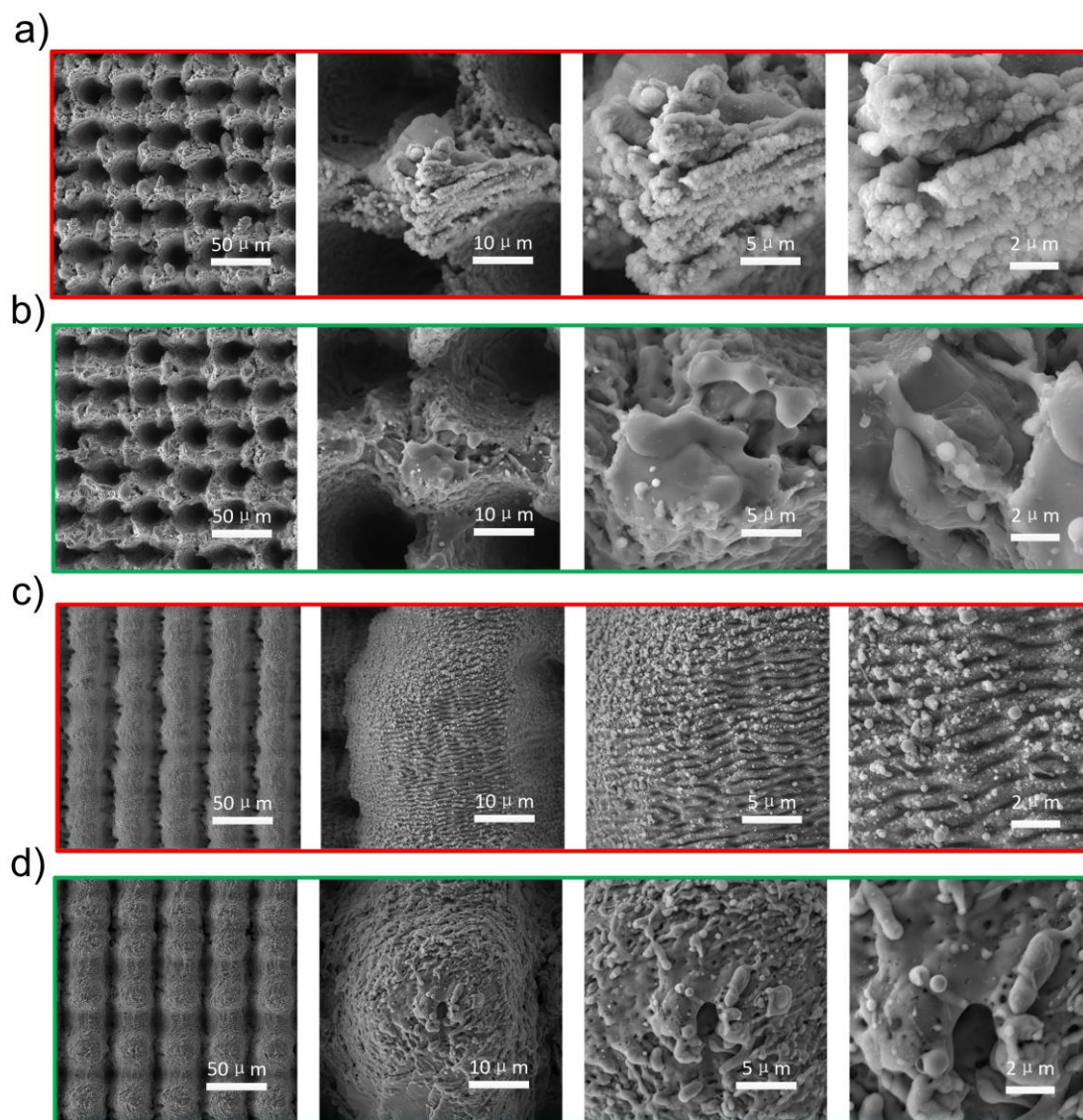


Figure S6. a), c) SEM images of Micro-nano structures of the SiO₂ wafer (a) and copper (c) samples after first laser irradiation. b), d) SEM images of Micro-nano structures of the SiO₂ wafer (b) and copper (d) samples after second laser irradiation.

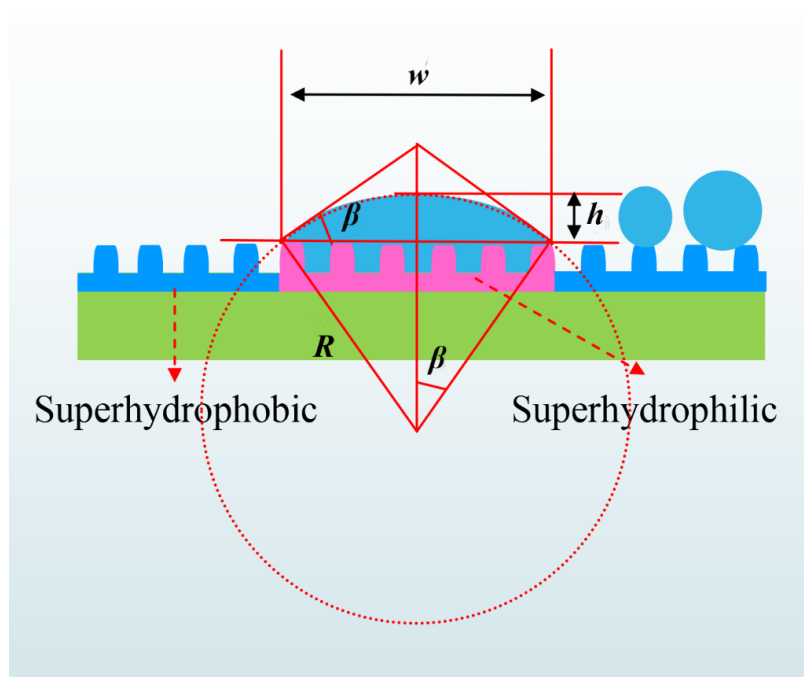


Figure S7. Cross-sectional view of water profile on the channel (or on the circle water reservoir).

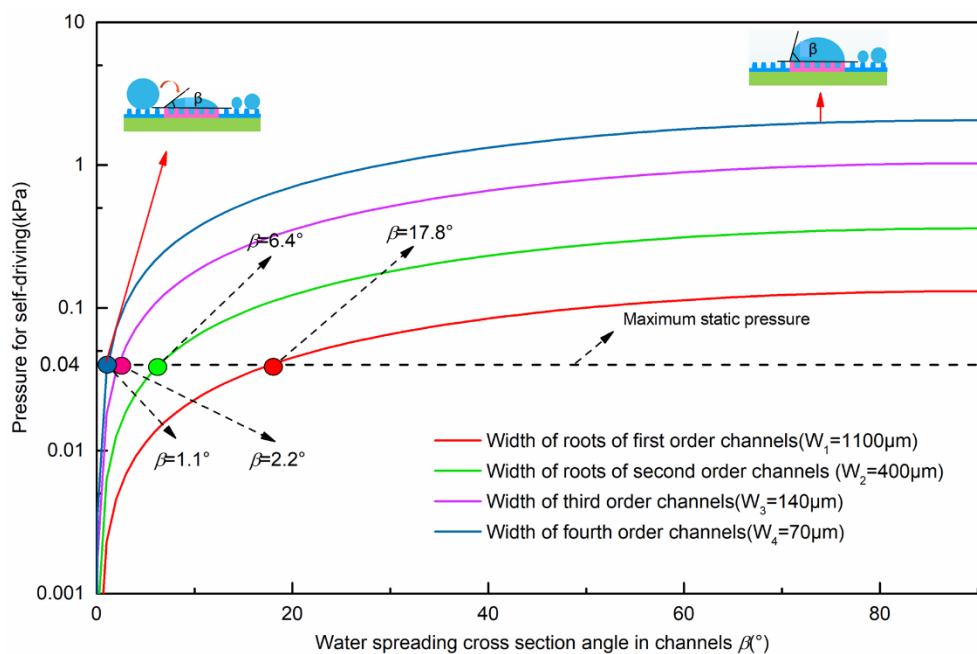


Figure S8. Theoretically calculated relationship between the pressure for self-driven transportation and the water-spreading-cross-section angle in the four channels.

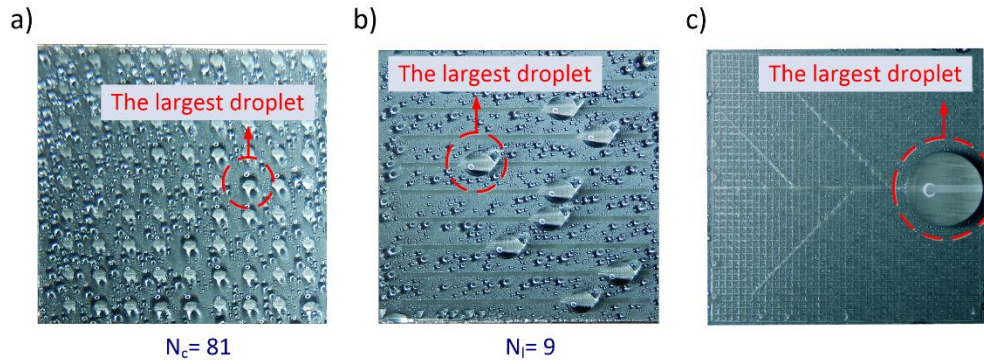


Figure S9. The images of the largest droplets on the circle patterned(a), aequilate channel(b) and venation network(c) surface. N_c and N_l represent the number of the circle patterns and aequilate channels, respectively.

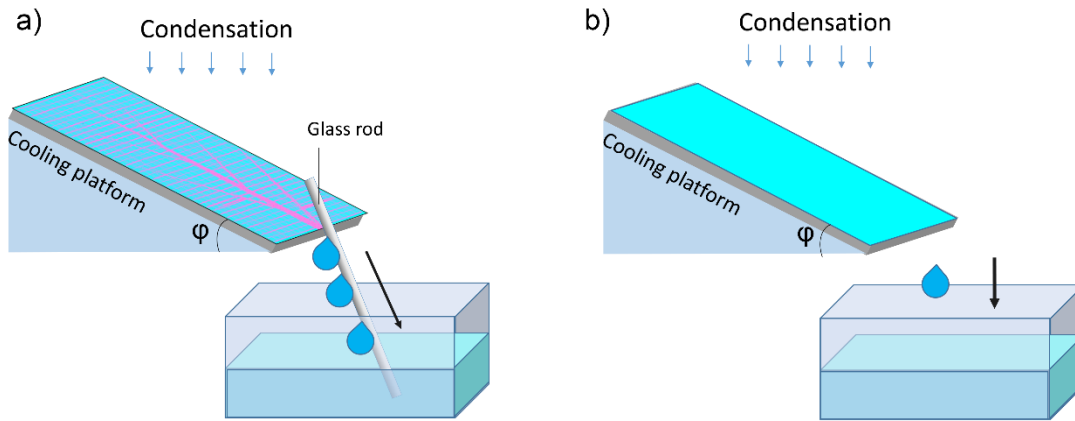


Figure S10. Schematic illustration of the method used to quantitatively measure the water collection efficiency of the venation network(a) and superhydrophobic(b) surfaces. For the venation network surface, the condensed water would accumulate at the end of the 1st channel. To better harvest the condensed water, a glass rod was used to guide the water into to the bottom container. For the superhydrophobic surface, the condensed water would dispersedly distribute on the surfaces and then roll into the bottom container. The total weight of the collected water was measured after 1 h to calculate the water-collection efficiency.

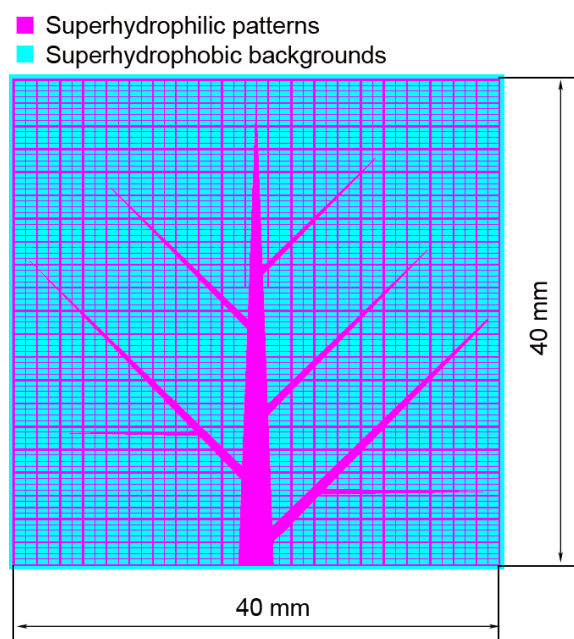


Figure S11. The diagram of square venation network with a dimension of $40 \times 40 \text{ mm}^2$.

Supplementary Table

Table S1. Specific laser processing parameters for fabricating different materials.

Materials	Processing	Laser Fluence (J/cm ⁻²)	Scanning Speed (mm/s)	repetition rate	Pulse Duration	Scanning Route	Scanning Interval (μm)	Repeat number
Aluminum alloy	First Irradiation	0.76	40	400kHz	800fs	Crossed lines	35	1
	Second Irradiation	0.67	200	30kHz	12ns	Paralell lines	35	1
Copper	First Irradiation	2.8	100	400kHz	800fs	Crossed lines	40	1
	Second Irradiation	1	200	30kHz	12ns	Paralell lines	40	1
SiO ₂ wafers	First Irradiation	2.8	100	400kHz	800fs	Crossed lines	40	1
	Second Irradiation	0.67	400	30kHz	12ns	Paralell lines	40	1

The SiO₂ wafers with a diameter of 100±0.2mm were purchased from JAN TECH. The thicknesses of the wafers are 500±25μm. The thicknesses of the oxide layers are 300±20nm. The surface of the wafer possesses a mirror finish. They were cleaned ultrasonically with ethanol before laser treatment.

The copper samples (99.9% purity) with a dimension of 40×40×1 mm³ were purchased from Chongqing Renxin Metal Materials Co., Ltd. They were mechanically polished to mirror finish and cleaned ultrasonically with ethanol before laser treatment.

Table S2. Apparent water contact angle (CA) and sliding angle (SA) for the aluminum surfaces used in the experiments.

surface	CA(°)	SA(°)
Superhydrophilic	0	—
superhydrophobic	162	2
Superhydrophilic/ superhydrophobic	0/162	—/2

All the value is obtained from at least three independent measurements and the standard deviation is ~1.