Directional transport of high-temperature Janus droplets mediated by structural topography

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**Supplementary Movies**

**Supplementary Movie 1** The dynamics of a water droplet (radius $R_o = 1.42$ mm)
impinging upon a gradient surface with sparser region placed on the left side and denser region placed on the right side in the experiment and this image coordinates. The temperature of the substrate was set at 265 °C and the droplet was released from a vertical distance of 5 cm, corresponding to \( We = 19.3 \). Upon collision, the droplet stayed in a mixed boiling-Leidenfrost (Janus) state, and subsequently vectored toward contact boiling region.

**Supplementary Movie 2|** Symmetric droplet motion dynamics on the gradient surface with temperature of 225 °C and 310 °C, respectively \( (We = 19.3) \). The droplet stayed in contact boiling state under 225 °C and Leidenfrost state under 310 °C, and the directional movement was suppressed.

**Supplementary Movie 3|** Directional droplet motion toward the zones with higher Leidenfrost points \( (L = 60 \, \mu m \text{ and } 100 \, \mu m) \). For this surface, these zones with the densest posts are arranged on the right of the surface. \( T = 250 \, \text{°C} \).

**Supplementary Movie 4|** Directional droplet motion toward the zone with \( L = 100 \, \mu m \). \( T = 270 \, \text{°C} \).

**Supplementary Movie 5|** Directional droplet motion toward the zones with \( L = 60 \, \mu m \text{ and } 100 \, \mu m \), which are arranged in the diagonal direction, respectively. \( T = 250 \, \text{°C} \).

**Supplementary Movie 6|** Directional droplet motion toward the zone with \( L = 100 \, \mu m \). In this case, these zones with the densest posts are arranged in the diagonal direction. \( T = 270 \, \text{°C} \).
Supplementary Figures

Supplementary Figure 1| Selected snapshots showing the symmetric spreading of a droplet impinging upon the gradient surface under ambient condition.
Supplementary Figure 2 | The variation of the maximum displacement of the centroid of an impinging droplet as a function of the Weber number. The experiment was conducted at room temperature. The error bars correspond to the standard deviation of the measurements.
Supplementary Figure 3 | Contact time analysis. a, SEM image of the control sample with two-tier roughness that exhibited superhydrophobicity. The insert shows the close-up image of the nanowire arrays covering the entire surface. b, The effect of the substrate temperature on the contact time of the droplet impinging upon the solid surface. For the superhydrophobic surface, the contact time is constant, following the scaling law: 

$$\tau_T \sim 2.6(\rho D_0^3/8\gamma)^{1/2}.$$ 

However, as the droplet impacts the gradient surface at the Janus thermal state, the contact time $$\tau_T$$ at any $$T$$ is extended due to the localized boiling state on sparse posts. Various $$We$$ numbers ($$We = 15.4, 19.3, 23.2$$ and $$27.0$$) were tested showing the same trend of the contact time. The error bars denote the standard deviation.
of the measurements.

**Supplementary Figure 4 | Effect of the droplet size on the directional motion of droplet.**

**a,** Selected snapshots showing the directional motion of impacting droplet with $R_0 = 1.01$ and 1.42 mm, respectively. $T = 240 \, ^\circ\text{C}$. **b,** The variations of the maximum displacement factor $k$ with respect to the substrate temperature. The temperature window for the Janus state is sensitive to the droplet size, although there is no considerable difference in the maximum $k$. The error bars denote the standard deviation of the
Supplementary Figure 4 | Effect of the droplet size on the directional motion of droplet. 

a, Selected snapshots showing the directional motion of impacting droplet with $R = 1.01$ and 1.42 mm, respectively. 

b, The variations of the maximum displacement factor $k$ with respect to the substrate temperature. The temperature window for the Janus state is sensitive to the droplet size, although there is no considerable difference in the maximum $k$. The error bars denote the standard deviation of the measurements.

Supplementary Figure 5 | Vapor flow analysis. 

a, Schematic diagram showing the outward vapor flow in the thin vapor film above the pillar tips (red arrows) and inside post arrays (black arrows). 

b, Schematic of the top-view of a Leidenfrost droplet impacting on post arrays. 

c, Diagram of outward flow resistances corresponding to two different vapor layers.
Supplementary Figure 6| The estimation of the thickness of vapor layer above the post arrays. The y-axis is \( y = \mu_v, k_v (T_L - T_{\text{sat}}) / \left(2 \Delta P, h_{\text{fg}}, \rho_v, H^2 \right) \) and the x-axis is \( x = L^2 H^2 / \left[ r_c^2 (L^2 + H^2) \right] \), and thus the slope of plot is \( \delta / H \). Here, the slope of the straight line is \( 0.052 \pm 0.0009 \), corresponding to the thickness of vapor layer above the post arrays being \( \delta = 1.04 \pm 0.18 \mu m \).
**Supplementary Figure 6** | The estimation of the thickness of vapor layer above the post arrays. The y-axis is \( \left( \frac{v}{2} \right) \left( \mu \rho \right) \left( \Delta T \right) \left( \frac{v}{2} \right) \), and the x-axis is \( \left( \frac{c}{2} \right) \left( L \right) \left( H \right) \), and thus the slope of plot is \( \frac{\mu}{H} \). Here, the slope of the straight line is \( 0.052 \pm 0.0009 \), corresponding to the thickness of vapor layer above the post arrays being \( \Delta \mu \pm 0.18 \) m.

**Supplementary Figure 7** | The schematic drawing of the droplet contact line. The overall driving force of the droplet with Janus thermal state (Leidenfrost and contact boiling state) is achieved from the unbalanced Young’s force (red arrow) over the contour \( s \): \( F = \gamma \int (\cos \theta_1 - \cos \theta_2) ds \).
Supplementary Figure 8 | Effect of the preferential droplet motion on the heat transfer coefficient. a, The variation of the time taken for an impinging droplet to be fully evaporated under different temperatures (or wetting states). Four control samples with post-to-post spacing of \( L = 100 \mu m, 60 \mu m, 40 \mu m \) and 30 \( \mu m \) were tested. At the lower temperature range (\( T < 210 ^\circ C \)), the evaporation completes at very short timescale (~ 0.5 s) due to extreme boiling whereas the evaporation time in the Leidenfrost condition is two orders of magnitude larger than that in the CB regime. b, Comparison of the heat transfer coefficients for droplets in different wetting states. The heat transfer
The variation of the time taken for an impinging droplet to be fully evaporated under different temperatures (or wetting states). Four control samples with post-to-post spacing of $L = 100 \, \mu\text{m}$, $60 \, \mu\text{m}$, $40 \, \mu\text{m}$ and $30 \, \mu\text{m}$ were tested. At the lower temperature range ($T < 210 \, ^\circ\text{C}$), the evaporation completes at very short timescale ($\sim 0.5 \, \text{s}$) due to extreme boiling whereas the evaporation time in the Leidenfrost condition is two orders of magnitude larger than that in the CB regime.

Comparison of the heat transfer coefficients for droplets in different wetting states. The heat transfer coefficient of a boiling droplet on the surface with $L = 100 \, \mu\text{m}$ is estimated to be $> 1460 \, \text{W/(m}^2 \cdot ^\circ\text{C)}$, which is much larger than that of a Leidenfrost droplet on the surface with $L = 30 \, \mu\text{m}$ ($109 \, \text{W/(m}^2 \cdot ^\circ\text{C)}$). The error bars denote the standard deviation of the measurements.