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Nanoarray-Embedded Hierarchical Hydrophobic Surfaces for Enhancing Durable Dropwise Condensation

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ABSTRACT

Liquid accretion control plays a key role across a wide range of industrial applications, such as anti-icing, power generation, sewage treatment, water desalination, and energy harvesting. In condensation system, durable dropwise condensation of saturated vapor for heat transfer and energy saving in extensive industrial applications. While numerous superhydrophobic surfaces can promote steam condensation, maintaining discrete microdroplets on surfaces without the formation of a flooded filmwise condensation at high subcooling remains challenging. Here, we report the development of carbon nanotube array-embedded hierarchical composite surfaces that enable ultra-durable dropwise condensation under a wide range of subcooling temperatures (ΔT_{sub} = 8 K–38 K), which outperforms existing nanowire surfaces. This performance stems from the combined strategies of the hydrophobic nanostructures that allow efficient surface renewal and the patterned hydrophilic micro frames that protect the nanostructures and also accelerate droplet nucleation. The synergistic effects of the composite design ensure sustained Cassie wetting mode and capillarity-governed droplet mobility (Bond number < 0.055) as well as the large specific volume of condensed droplets, which contributes to the enhanced condensation heat transfer. Our design provides a feasible alternative for efficiently transferring heat in a vapor environment with relatively high temperatures through the tunable multiscale morphology.

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