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Roughness-based Superhydrophobic Surfaces: Fundamentals and Future Directions

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Superhydrophobicity of rough surfaces has attracted global interest through the past decade. There are naturally occurring instances of such surfaces, e.g., lotus leaves, which led to the popular term “lotus effect.” Numerous applications in wide ranging areas such as drag reduction, self-cleaning, heat exchangers, energy conversion, condensation, anti-icing, textile, desalination, etc., are being explored by researchers worldwide. The signature configuration for superhydrophobicity has been “bead-like” drops on rough surfaces that roll-off easily. This becomes possible if the liquid does not impale the roughness grooves, and if the contact angle hysteresis is low. Finding appropriate surface roughness is therefore necessary. A thermodynamic framework to enable analysis of this problem will be presented. It will be noted that the success of rough superhydrophobic substrates relies on the presence of gas pockets in the roughness grooves underneath the liquid. These gas pockets could be those of air from the surrounding environment. Current design strategies rely on the availability of air. However, if the rough substrates are fully submerged in the liquid then the trapped air in the roughness grooves may not be sustained. A design approach based on sustaining a vapor phase of the liquid itself in the roughness grooves, instead of relying on the presence of air, will be presented. The resulting surfaces, referred to as vapor stabilizing substrates, are deemed to be robust against wetting transition even if no air is present. Applications of this approach include low drag surfaces, nucleate boiling at dramatically low superheats, among others. The concept can be generalized to other transitions on the phase diagram, thus enabling the design of rough surfaces for phase manipulation in general.