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Design of lotus-simulating surfaces: Thermodynamic analysis based on a new methodology

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ABSTRACT

Superhydrophobicity has increasingly attracted the specialists' attention owing to its inspiring applications. Currently, superhydrophobic surfaces have been prepared by different techniques. However, microscopic mechanisms responsible for contact angle hysteresis (CAH) and free energy barrier (FEB) are not yet completely clear. In this study, we propose an intuitive free energy (FE) thermodynamic analysis on superhydrophobic surfaces with a micro-/nano-scale pillar structure based on a new method with the purpose of determining and explaining CAH with use of changes in free energy (CFE) and FEB. The relationships between CA, CAH, CFE, FEB and micro-/nano-structure parameters are established by numerical simulation. The dependency of the hydrophobicity on the micro-/nano-scale is quantitatively discussed. Based on changes in FEB, the possible transition from non-composite to composite wetting state is innovatively developed. These will play an important theoretical guiding role in fabrication of superhydrophobic surfaces.

1. Introduction

1.1. A brief description of methods in this study

A study of natural and bio-mimetic artificial surfaces with superhydrophobicity (CA > 150°, CAH < 10°) has been attracted interest of science and industry due to its potential application value. Theoretically, different models have been established to simulate systems of superhydrophobic surfaces and investigate its macro-/microscopic wetting mechanism. There are three classical equations, Young's [1], Wenzel's [2,3], and Cassie–Baxter's equation [4–7], which described the wetting states of ideal smooth surfaces, rough homogenous surfaces and rough heterogeneous surfaces, respectively. Experimentally, ideal superhydrophobic surfaces have been fabricated with different materials and by different techniques [8], and applied in coating fields since the German scientists Barthlott and Neinhuis [9] as well as the Chinese scientists Jiang and Feng [10] revealed the secret of the "lotus effect" by SEM and ESEM, respectively. From a methodology point of view, it has been manifested mainly in two aspects as follows: firstly, by studying static or dynamic wetting behavior from macroscopic, such as intrinsic or apparent CA (including receding, advancing, and equilibrium CAs), CAH, sliding angle (SA) [2–4,11–13], the effect of changes in droplet volume on CA or CAH [14], and continuity of three-phase contact line [15–18]; and secondly, by studying micro-/nano-scale surface topography, wetting states and wetting mechanisms, such as surface roughness factors as a function of micro-/nano-scale parameters together with its influence on the superhydrophobicity [2–4,13,19–21], the possibility of making high-contact angle, rough surfaces from low-contact-angle materials [22], composite or non-composite wetting states along with transition between them [12,13,22,23], anisotropic wetting behavior originating from superhydrophobic surfaces due to surface micro-/nano-structures [24], as well as tunable wettability [25]. This was followed by descriptions of the microscopic wetting mechanism by using surface tension, free energy (FE) and free energy barrier (FEB), physical and chemical adsorptions, along with capillary forces [26].

1.2. Techniques widely used for preparing superhydrophobic surfaces

Based on the research results on the "lotus effect", the wettability of solid surfaces mainly depends on two factors: surface chemical composition and structural roughness. As a result, superhydrophobic surfaces, as a lotus-simulating structure, may be generally fabricated through two methods which are providing the rough surface structure using hydrophobic materials, then modifying the low-surface-energy materials on the roughened surfaces, being the key to fabrication.

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