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Microfabricated textured surfaces for super-hydrophobicity investigations

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Abstract

The natural hydrophobicity of surfaces can be enhanced if they are micro-textured. This is due to air trapped in the structure, which provides the deposited drop with a composite surface made of solid and air on which it is resting. Here, we give evidence for this effect using a forest of micro-pillars which allows us to control the micro structure density under the drop, and thus the degree of super-hydrophobicity. For this purpose, silicon wafers were firstly patterned by conventional photolithography techniques. After deposition of an aluminium layer, the samples were subjected to a deep reactive ion etching (DRIE) with the "Bosch process" in order to achieve high aspect ratios ($\geqslant 10$). However, this state is not always the most stable situation for a drop on a hydrophobic surface: the drop can also fill up the micro-structure. We have been able to observe these two super-hydrophobic states on our surfaces and to characterize advancing and receding contact angles for both of them.

Keywords: Microstructures; Deep reactive ion etching; Wetting properties; Super-hydrophobicity

1. Introduction

In nature, several plants or animals show remarkable superhydrophobic properties: water meets their surfaces with a very high contact angle, as sketched in Fig. 1. Values as high as 160° (on Lotus leaves) or even 170° (on water striders legs) have been reported. Super-hydrophobicity is the origin of the purity of lotus: water drops roll on the leaves and carry dust particles – a mechanism often referred to as self-cleaning. For the water striders, super-hydrophobicity al-

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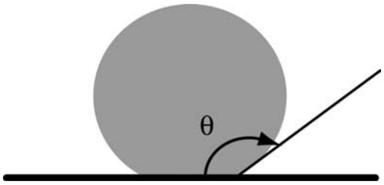

Fig. 1. Definition of a contact angle θ for a water drop on a solid substrate.

lows these insects to float (and to walk) safely on water surfaces. All these different surfaces are made with a hydrophobic material (a wax) and present textures, such as bumps and/or hairs at the scale of 100 nm to 10 μm (Fig. 2) [1]. This phenomenon can have very useful applications such as protecting surfaces from rain, self-cleaning properties for windows or low friction devices in microfluidics.

Thus, hydrophobic surfaces (like wax or Teflon) can be made super-hydrophobic by creating a texture on them. In this paper, we give evidence for this effect using forests of micro-pillars, which allows us to control the micro structure density under the drop, and thus the degree of super-hydrophobicity. These synthetic surfaces are obtained by using microfabrication techniques. They are made by structuring silicon wafers with classical lithography and deep reactive ion etching (DRIE) techniques. Then, contact angles of water drops on such surfaces are measured, allowing us to check the correlation between the wetting properties and the surface geometry.

2. Models

When a drop is deposited on a super-hydrophobic surface, either it fills the structure (Wenzel state) or it sits on the top of the structures (Cassie state), as sketched in Fig. 3. In the Wenzel state, the apparent contact angle θ^* on the rough surface is related to the contact angle θ on the same surface yet flat by the relation [2]

$$\cos\theta^* = r\cos\theta, \tag{1}$$

where r is the roughness of the material, defined as the ratio between the true surface area over the apparent flat one.

In the Cassie state, the drop behaves as a fakir on a bed of nails: the drop sits on a composite surface made of solid and air, and only interacts with the top of the asperities. The apparent contact angle θ^* on such a surface is an average between θ (defined above) and 180°, the contact angle on air. The average is made on the cosines, and weighed by the surface fraction ϕ_S and by the air fraction $(1 - \phi_S)$ in contact with the drop. Hence, we get the Cassie–Baxter relation [3]:

$$\cos\theta^* = \phi_S(1 + \cos\theta) - 1. \tag{2}$$

The surface is all the more hydrophobic since ϕ_S decreases.

Practically, a surface is not defined by a unique contact angle: for a given system, an interval of contact angles is observed, the difference between the largest (so-called advancing) and the smallest (so-called receding) ones being called the contact angle hysteresis (Fig. 4). A drop with a very low hysteresis easily rolls off an inclined surface.

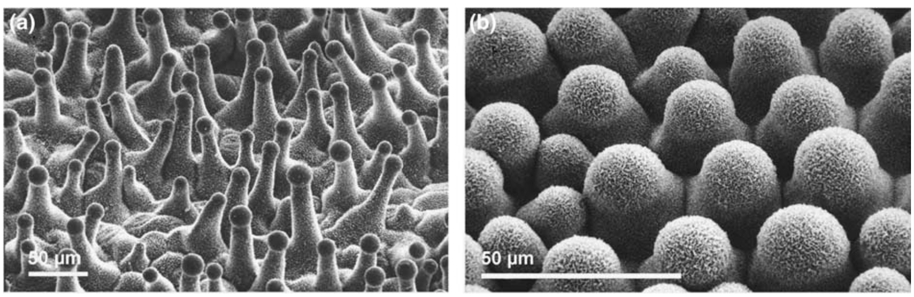

Fig. 2. Example of micro-structures on natural leaves, as seen by electron microscopy. (a) Liriodendron (magnolia), (b) *Colocasia esculenta* (elephant ear). (Courtesy of Peter Wagner and Christoph Neinhuis.)