ABSTRACT

Imbibition of Micro-Patterned Surfaces
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Surfaces with micro structures are ubiquitous in nature. Lotus leaves are one example of those. Lotus leaves repel well water drops with their super-hydrophobic surfaces due to micro structures on the surfaces [1]. By virtue of the progress of micro-fabrication technologies, wettability of micro-patterned surfaces has actively been studied in these days for both hydrophilicity (or lipophilicity [2,3]) and hydrophobicity [4] (or lipophobicity).

Understanding of the imbibition of hydrophilic (or lipophilic) micro-patterned surfaces is especially important not only from physical but also from practical and industrial viewpoints. One of the simplest examples of imbibition may be capillary rise; when an end of a capillary tube is touched with wettable liquid, the liquid rises up inside the tube; the statics and dynamics of the phenomenon are experimentally and theoretically understood; in particular, the rising height z scales with the square root of elapsed time t in the viscous regime. This power law has also been found for the imbibition of micro-patterned surfaces [2], while another scaling law $z \sim t^{1/3}$ has been found for the imbibition of another type of textured surfaces [3] ($z \sim t^{1/3}$ was also reported for the dynamics of capillary rise into corners [5,6]). The difference between the exponents appearing in the scaling laws seems to be caused by geometries and sizes of micro structures on surfaces, however the crossover between the two dynamics has yet to be clarified.

We experimentally and theoretically investigate imbibition of two different micro-patterned surfaces as follows:

(1) Capillary rise on the surface of a leg of a small animal (wharf roach) and on the surfaces mimicking it [7] (Chapter 6). Although imbibition dynamics generally slows down with time, *e.g.*, $z \sim t^{1/2}$ or $z \sim t^{1/3}$, we found a non-slowing down dynamics on a coarse-grained level for capillary rise on the surface of a sixth leg of the small animal, wharf roach; imbibition length scales linearly with elapsed time, $z \sim t$. This non-slowing down dynamics has advantages for a long-distance transport. Motivated by this unusual feature, we fabricated micro-patterned surfaces partially mimicking the surface of the sixth leg and carried out imbibition experiments on them. Contrary to our expectation, we could not reproduce non-slowing down dynamics; the imbibition length scales with the square root of elapsed time. However, we confirmed that a composite model developed in this study well de-

scribes experimental results. Furthermore, we found the capillary rise on the hybrid surfaces partially mimicking the surface of the leg is faster than the capillary rise on non-hybrid surfaces.

(2) Capillary rise into "open-capillary" [8] (Chapter 7). We carried out experiments with an open capillary tube whose cross-section is rectangular on a submillimeter scale, and then observed two regions in the tube: a liquid column in which the open capillary is almost completely filled with the liquid, and a precursor film that proceeds ahead of the liquid column. For the liquid column, we confirmed that scaling laws we developed for the statics and for the dynamics in the initial (viscous) and final (visco-gravitational) regimes well describe the experimental results. For the precursor film, we confirmed that its length h scales with $t^{1/3}$. Thus, the progress of the precursor film is regarded as capillary rise into the corners of the open capillary [5,6]. Furthermore, we demonstrated two applications, multiple color changes of the BTB solution and the expression of Green Florescence Protein (GFP), in older to show capabilities of devices that utilize open channels and that are driven not by pumps but by capillary force. We consider that our open-capillary devices are promising for new applications.

This thesis is organized as follows: first, capillary phenomena and fluid dynamics are briefly reviewed. Second, we discuss the statics and dynamics of capillary rise and previous works on imbibition of micro-patterned surfaces. Third, we describe imbibition of two different micro-patterned surfaces (chapter 6 and 7), which is the main part of this thesis. Finally, we summarize the content and discuss some future directions.

References

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