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Directional wetting on chemically patterned substrates

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ABSTRACT

The directional wetting behavior of chemically defined stripe-patterned anisotropic surfaces is presented. The equilibrium shapes of asymmetric droplets, arising from patterns of alternating hydrophilic and hydrophobic stripes with dimensions in the low-micrometer range, are investigated in relation to the stripe widths. Owing to the well-defined small droplet volume, the equilibrium shape as well as the observed contact angles exhibit unique scaling behavior. Additionally, we investigate the motion of liquid from surface areas with low macroscopic wettability toward areas with a higher wettability. The density of self-assembled fluoroalkylsilane monolayers in terms of the number and width of the stripes, as defined by the chemical patterning, proves to be of paramount importance. Linear and radial patterns are presented, which induce liquid movement along the chemically defined stripes giving rise to a macroscopic gradient in surface energy.

1. Introduction

The ability to control liquid behavior on surfaces has attracted the attention of a large scientific community, including fluid physicists, materials and interface scientists. Such smart surfaces with artificially designed wetting characteristics are highly relevant for a number of application areas, ranging from micro- or nanofluidics to car windows. Numerous theoretical and experimental studies have been carried out on chemically heterogeneous [1–10] and topographically structured surfaces [11–16].

A technologically relevant application of smart surfaces to control wettability concerns the nozzle plate in inkjet print heads. Apart from conventional document printing [17–19], possible combination of inkjet technology with liquids other than conventional inks enable new approaches in electronic circuit printing [20], manufacture of liquid crystal-based screens [21], displays [22], solar cells [23], data storage [24], optical fibers [25], drug dispensing [26], and many more. To further improve the printing speed and resolution, while simultaneously maintaining a high quality of the produced prints, the miniaturization of the inkjet head itself is required. Enhanced miniaturization poses new challenges to be solved, ranging from (i) improved ink channel design to (ii) development and optimization of piezo-materials to (iii) interference of the wetting layer on the nozzle plate with the firing of droplets.

In this contribution, we focus on a possible solution for problems imposed by the wetting characteristics of the nozzle plate. More specifically, we aim at designing suitable patterned surface coatings to control the motion of the residual ink layer. A promising approach comprises the creation of a surface tension gradient by combining two chemical species with distinctly different surface energies. One should be hydrophobic while the other should be hydrophilic, i.e. non-wetting and wetting, respectively, for the ink used in the printing process. The overall surface tension should increase with increasing distance from the nozzle orifice. Ink droplets in contact with a spatially varying surface energy on the nozzle plate will move in the direction of high surface tension and thus away from the nozzle.

A possible way to create such an energy gradient in a controlled way consists of applying a pattern made of stripes of alternating wettability. Changing the relative widths of stripes enables tuning the overall surface energy, while using a well-defined geometry creates a preferential direction for droplet motion parallel to the stripes. In the next section we first describe the static behavior of liquid droplets on such anisotropic stripe patterned surfaces with distinctly different wetting characteristics in orthogonal directions. Experimental results are quantitatively compared to simulations using both Surface Evolver and the lattice Boltzmann approach. Subsequently, we describe how such patterns may be used to define a wettability gradient and therewith enable control over the motion of liquid on these surfaces. After reviewing our results on linear patterns, we show how radial patterns can be used to control liquid motion in more realistic, application inspired geometries.

2. Substrate modification

The patterns employed in our studies consist of alternating hydrophilic and hydrophobic stripes (fluoroalkylsilane

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