Wetting morphologies on topographically structured substrates: a possible way to open microfluidics

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Fundamental requirement of microfluidic based devices is the accurate control of minute amounts of liquid. As an alternative to conventional microfluidics where liquid flows in a solid matrix we consider open microfluidics, where liquid is guided along prefabricated grooves. We study the equilibrium wetting morphologies, transport liquid along grooves by switching between different equilibrium morphologies, and explore the underlying dynamics.

Liquids are generally attracted to linear steps or grooves as we explicitly show for grooves with triangular and rectangular cross section. The basic wetting morphologies in triangular grooves are drops, elongated filaments with positive mean curvature and liquid wedges with negative mean curvature [1]. The appearance of these equilibrium morphologies depending on geometry and wettability is in excellent agreement with numerical and analytical results and can be illustrated best in a morphological diagram. Similar basic wetting morphologies exist for rectangular grooves [2]. But due to the larger number of corners the variety of wetting morphologies in rectangular grooves is increased compared to triangular grooves.

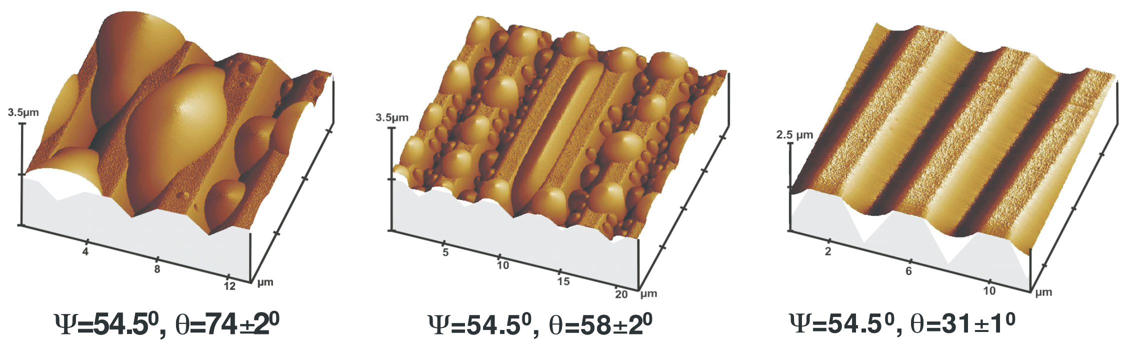

Fig. 1: *Basic equilibrium wetting morphologies of vapor deposited polystyrene morphologies in triangular grooves. From left to right: drops, filaments with positive mean curvature, and liquid wedges.*

When combined with a technique, which allows to tune either the contact angle or the geometry of the grooves, we can switch between different equilibrium wetting morphologies. Using AC electrowetting we reversibly tune the contact angle of an aqueous solution on a hydrophobized silicon substrate from about 95deg to about 45deg. When a droplet is placed on a grooved substrate and the contact angle reduced below the critical filling threshold, the liquid spontaneously imbibes the grooves. Fig. (2) shows optical micrographs of electrowetting induced groove filling experiment. Due to the fact that we apply AC voltage and due to the finite conductivity of the liquid, the voltage drops along the liquid filament resulting in a finite filament length, where the voltage at the tip equals the threshold voltage for the groove filling [3].

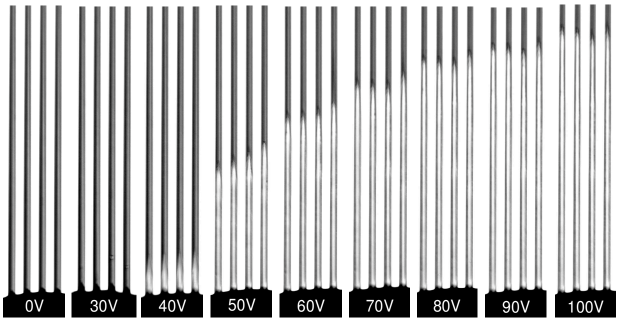

Fig. 2: *Optical micrographs of electrowetting groove filling experiment in triangular grooves as function of the applied voltage.*

In case of rectangular grooves the groove filling is reversible and the filament recedes back to its feeding drop when the applied voltage is switched back to zero. The groove filling and draining is purely capillary given and can be described by the Washburn equation (filament length ~ $t^{1/2}$) whereas the static contact angle has to be replaced by the locally varying apparent contact angle [4]. In triangular grooves, however, the liquid filaments rather decay into single, equally spaced droplets when the apparent contact angle is increased above the filling threshold, see Fig.(3). This instability is driven by the local variation of the Laplace pressure with filament width. It may be viewed as a generalization of the Rayleigh-Plateau instability [5].

In-situ AFM experiments reveal the decay time (τ) of the liquid filaments into single drops. The decay time varies linearly as a function of filament width. A careful analysis of the decay time for different filament widths give an estimate of a the slip length since slip is expected to dominate the instability dynamics provided the filament width is of the same order as the slip length.

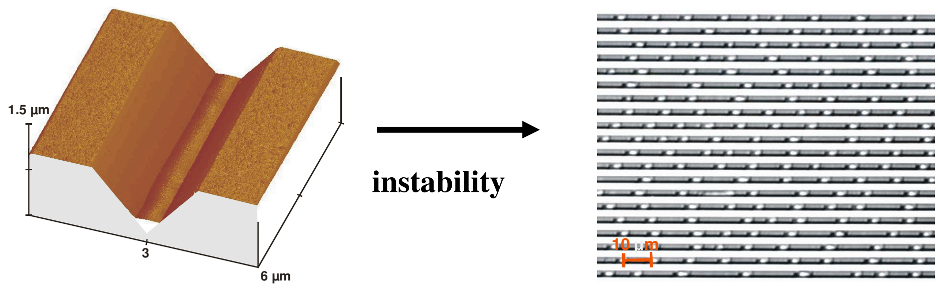

Fig. 3: *Instability of a liquid filament in triangular grooves. The liquid filament with positive mean curvature is unstable and breaks into single equally spaced drops.*

[1] J.-C. Baret, M. Brinkmann, B. M. Law, S. Herminghaus, and R. Seemann, *submitted*
[2] R. Seemann, M. Brinkmann, E. J. Kramer, F. F. Lange, and R. Lipowsky, *Proc. Natl. Acad. Sci.* **102**, 1848 (2005)
[3] J.-C. Baret, M. Decré, S. Herminghaus, and R. Seemann, *Langmuir*, **21**, 12218 (2005)
[4] J.-C. Baret, et al, *Langmuir* (2007) *in print*
[5] K. Khare, M. Brinkmann, B. M. Law, E. Gurevich, S. Herminghaus, and R. Seemann, *submitted*