2.5D Nanofluidics: Grayscale Laser Lithography and Two Phase Flow in Non-Uniform Depth Nanochannels

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Standard micro and nanofabrication techniques naturally lead to planar structures made of a succession of flat sheets. However, devices including relief in their structures lead to new functionalities in many application fields by opening the path to topologies not accessible in 2D. In this work, we report a versatile method to fabricate silicon–glass nanofluidic chips with non-uniform channel depths in the range 20-500 nm and micrometer resolution in width. It is based on a single step of grayscale laser lithography and reactive ion etching [1]. Complex structures are fabricated such as slopes, step channels or pore networks that mimic nanoporous media (Fig. 1a).

In order to demonstrate the accuracy of our process, the kinetics of imbibition in straight nanochannels with non-uniform depth is measured and compared with a theoretical model (Fig. 1b). Quantitative agreement is obtained. Nevertheless, it is reported bubble trappings due to the thickening of corner liquid films at each crossing step.

Then, the method is used to fabricate a network of interconnected slits of non-uniform depth, a geometry mimicking a nanoporous medium in which a pressure step-controlled drainage experiment is performed, i.e., the immiscible displacement of a wetting fluid (liquid water) by a non-wetting one (nitrogen). The drainage patterns are analysed by comparison with simulations based on the invasion percolation algorithm (Fig.1c). The results indicate that slow drainage in the considered nanofluidic system well corresponds to the classical capillary fingering regime.

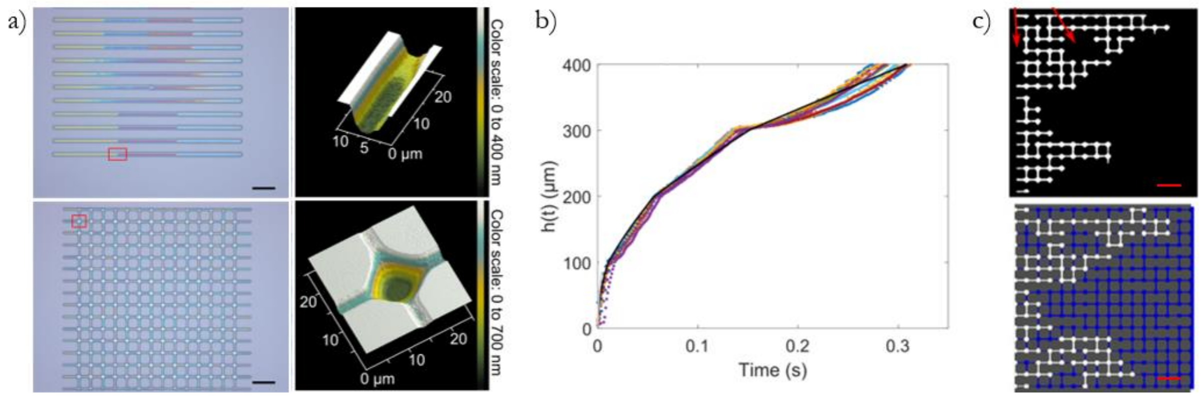

Figure 1: a) Picture after grayscale laser lithography and AFM image after etching. Top: varying depth nanochannels and zoom on a step. Bottom: pore network and zoom on a pore. b) Experimental (colored dots) and theoretical (black line) imbibition kinetics in a four steps nanochannel. c) Comparison between experiment (top) and pore network simulation (bottom) during the drainage of a 2.5D nanopore network. Red arrows point liquid cluster. Scale bar represents 50 µm.

References

[1] Naillon et al., "Quasi-static drainage in a network of nanoslits of non-uniform depth designed by grayscale laser lithography", Microfluidics and Nanofluidics, 21, 131 (2017)