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► **To cite this version:**

Antoine Naillon, Hajar Massadi, Rémi Courson, Pierre-François Calmon, Lucie Seveno, et al.. GRAYSCALE LITHOGRAPHY TO FABRICATE VARYING-DEPTH NANOCANNELS IN A SINGLE STEP. The 20th International Conference on Miniaturized Systems for Chemistry and Life Sciences, MicroTAS, CBMS, Oct 2016, Dublin, Ireland. hal-01391501

**HAL Id: hal-01391501**

**<https://hal.science/hal-01391501>**

Submitted on 7 Nov 2016

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# GRAYSCALE LITHOGRAPHY TO FABRICATE VARYING-DEPTH NANOCHANNELS IN A SINGLE STEP

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## ABSTRACT

We report a new, fast and versatile method to fabricate nanochannels with non-uniform depth in a single step, in the range 50-500nm. The process is based on maskless laser lithography to structure a photosensitive resist (PR). The lateral dimension can be as small as 2 $\mu$ m. Functional nanofluidic chips with slopes, steps, and pore networks mimicking a nanoporous medium were fabricated and tested.

**KEYWORDS:** nanofabrication, grayscale lithography, 3D lithography, nanofluidics

## INTRODUCTION

Fluidic architectures including several depths in a single chip open the path to interesting functions such as mixing, trapping or sorting. The drawback of standard fabrication methods is that they lead to a homogeneous thickness. Variable depths can be obtained in one step using a grayscale optical mask [1], a digital micro mirror device [2], or using 3D printing. However, the spatial resolution is quite low (>10 $\mu$ m) and the need to use specific masks prevents easily changing the design. E-beam lithography enables versatility in modifying designs and nanometer resolutions, but the process is time consuming and expensive. We have developed a direct laser writing method with nm-depth resolution.

## EXPERIMENTAL

As shown in Figure 1(left), a positive PR (ECI AZ 3012) is spin-coated at 3000RPM on a silicon wafer. The main step of the process consists of exposing the PR to a laser light (405nm) controlled dose. This is realized on a Dilase 750 machine (Kloe) by adjusting the laser power and beam scanning velocity. Beam spatial extension is set to 2  $\mu$ m. Process parameters are optimized to have a dose-dependent developing rate (Figure 1, right), which is the condition to precisely control grayscale lithography. Namely, scan velocity is inferior to 1 mm/s (to obtain a smooth surface), distance between successive laser scans is set to 1  $\mu$ m, soft-bake is longer than that in standard processes to reduce the PR contrast.

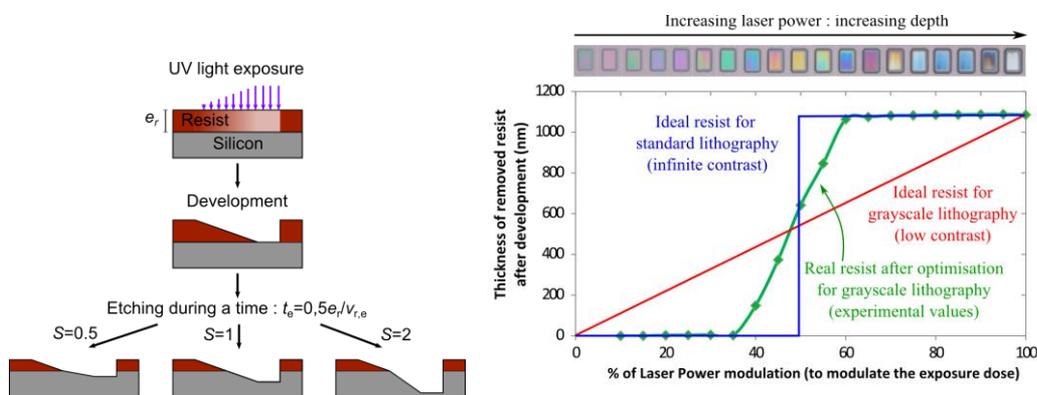


Figure 1: (Left) Scheme of the grayscale lithography process on thin positive resist. An etching selectivity higher than 1 increases the depth differences whereas the selectivity lower than 1 reduces them. (Right) Thickness of removed resist after development against laser power for constant writing velocity and spot diameter: theoretical and experimental contrast. Top images: microscope pictures, depth 0 - 1.1 $\mu$ m (true colors).

In these conditions, after developing, the remaining PR thickness is controlled by laser power (Figure 1(right)). Notably, quick quantitative control of the process can be made just by observing the color of the remaining PR (light interferences). Channels are then transferred into silicon by dry

etching. We choose plasma parameters to obtain a relative etching rate between silicon and the remaining PR (selectivity) lower than 1. With 1.1 $\mu\text{m}$  PR, it enables fabricating channels of depth 50-500nm in a single step, with many geometries accessible (Figure 2, left).

## RESULTS AND DISCUSSION

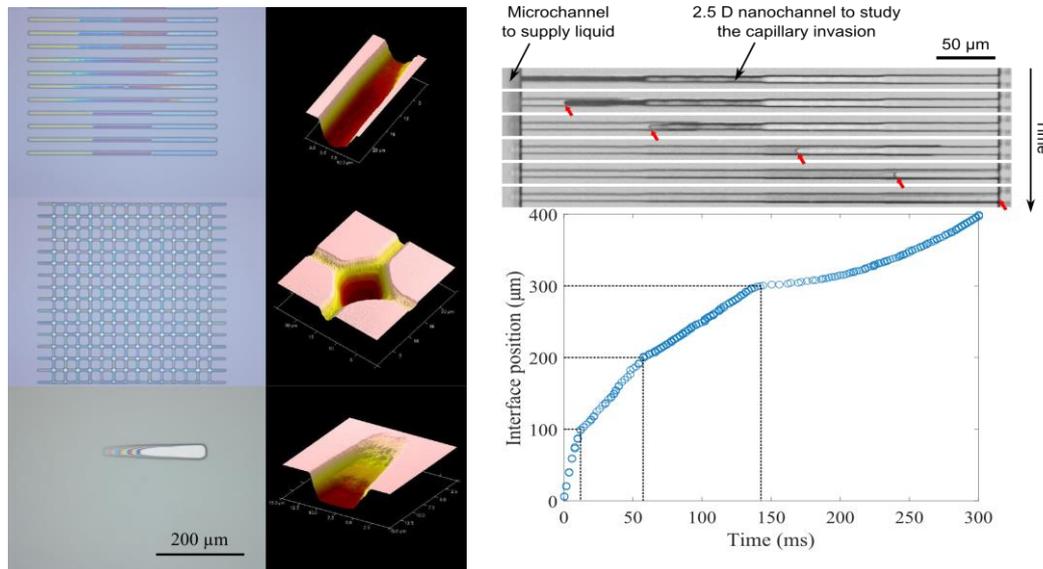


Figure 2: (Left) From top to bottom, picture of stair channels, pore network and a slope. On the left, microscope pictures of developed PR, true colors. On the right, AFM pictures of nanochannels in zones corresponding to fractions of left pictures. The colorbar scale ranged is 0-400nm, 0-600nm and 0-250nm from the top to bottom. (Right) On the top, pictures sequence of imbibition experiment of ethanol in a 4 stairs nanochannel from 250nm to 400nm depth. Small red arrows show the position of the meniscus. On the bottom, position of meniscus against time: at each stair, the kinetics of imbibition decreases because of the reduction of capillary pressure.

Our approach is thus a simple and versatile method to obtain any varying depth architecture in a single step. It is particularly suitable to fabricate nanochannel networks mimicking nanoporous media (see eg. architecture of Figure 2, middle), which are valuable tools to study processes occurring inside real rocks. As a proof of concept, we measure imbibition kinetics in a nanoslit including 4 different increasing depths (Figure 2, right). Meniscus velocity clearly changes at the steps. Semi-quantitative features are in line with predictions: slowing down at each step (decreased capillary pulling force), and almost constant velocity on each segment (hydraulic resistance dominated by already filled part).

## ACKNOWLEDGEMENTS

We thank ANDRA and CNRS for funding. This work was partly supported by LAAS-CNRS micro and nano technologies platform member of the French RENATECH network.

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