

Interfacial Direct Printing (IDP) of SU-8: Fabrication of Molds with Smooth Round Channels

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Summary:

In this study, we introduce a new process for the fabrication of microfluidic molds referred to as Interfacial direct printing (IDP). IDP allows the fabrication of smooth semi-round SU-8 structures on a glass slide, which is not possible with standard photolithography. The photoresist is deposited via a capillary on a moving substrate placed inside an oil bath, forming SU-8 lines with semi-round cross-section shaped by acting interfacial forces. After UV treatment and baking, the structures can be used for soft lithography. Round shaped channels are of particular interest for microfluidic organ-on-chip and diagnostic devices.

Keywords: printing, additive manufacturing, microfabrication, lithography, mold

Introduction

Photolithography has long been the gold standard to fabricate microfluidic molds used for replica molding. It provides very smooth and precise geometries, however, the structures have usually edged, often rectangular cross-sections. For many biological applications, notably organ-on-chip, circular geometries are preferred for cell cultivation. Indeed, they mimic the *in vivo* environment much better than edged forms. For example, spheroid/organoid assembly is favored in concave wells [1]. Also, rectangular structures provide zero flow regions, create additional shear stresses and can harm cells. Previous approaches to form round channels include CNC

implement, and require a cleanroom [4,5]. In this work, we present a new SU-8 deposition technique which allows the formation of channels with semi-round profiles, without the need for cleanroom equipment.

Interfacial direct printing (IDP)

The method builds on a previously introduced platform for liquid-in-liquid printing [6], here adapted to print viscous SU-8 photoresist. A substrate (a glass slide) is placed into a HFE 7500 oil bath (Figure 1a). A capillary is placed near the substrate, a gap g separating them. Application of pressure (P) pushes the SU-8 out, at the same time the glass slide moves at a defined velocity (v) relative to the capillary. When the parameters pressure, velocity and gap are tuned appropriately, the photoresist forms a continuous line on the substrate (Figure 1b). Due to the interfacial tension between the substrate, the oil and the photoresist, the deposited lines naturally forms a semi-circular shape. Subsequently, UV light is exposed on the substrate to cure the photoresist, and the oil bath is removed. The mold is then baked in an oven at 80°C overnight and can be used for soft lithography afterwards.

Printing results

Images of deposited lines are shown in Figure 2a,b. The cross-section of the line was measured with a profilometer (Figure 2c). Depending on the parameters, lines of different widths and heights are created. For example, by setting the pressure P to 200 mbar, the gap g to 20 μm , and the velocity v to 1 mm/s, the photoresist lines were 13.7 μm high and 105.9 μm wide, with

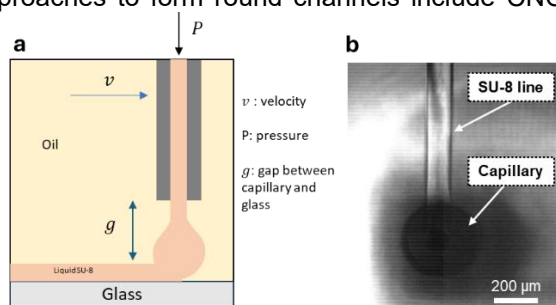


Figure 1: (a) Schematic illustrating the deposition of photoresist semi-round lines on substrate, by tuning three parameters, g , v and P . (b) Photo (top view) of line creation during deposition. Black spot is the capillary.

micromachining, laser ablation and 3D printing, which often result in irregular and rough surfaces [1,2,3]. Other methods include microfabrication techniques such as resist thermal reflow, or backside photolithography, but these lack good control over the final geometry, are hard to

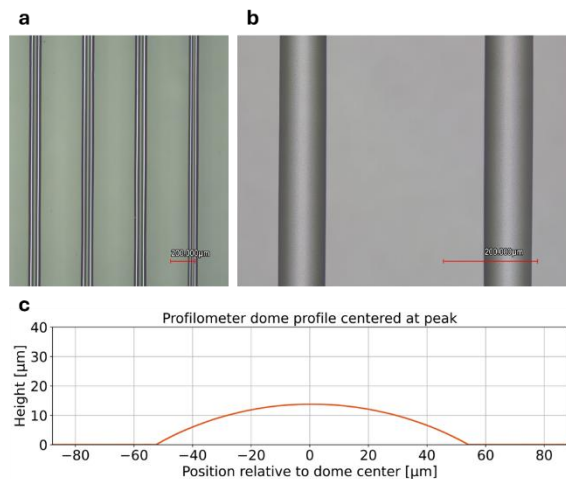


Figure 2: (a) Microscopy image of deposited lines 5x and (b) 20x. (c) Profilometer data displaying cross-section of a deposited line.

110.2 μm curvature radius, and 996 μm^2 in cross-section area. The contact angle θ was measured to be 29.2°. The cross-section area (A), height (h) and width (w) are dependent on pressure P and v as follows:

$$A = \frac{P}{R \cdot v'} \quad (1)$$

$$h = \sqrt{\frac{P \cdot (1 - \cos\theta)^2}{R \cdot v' \cdot (\theta - \sin\theta \cos\theta)}} \quad (2)$$

$$w = \sqrt{\frac{P \cdot 4 \sin^2(\theta)}{R \cdot v' \cdot (\theta - \sin\theta \cos\theta)}} \quad (3)$$

where R is the hydraulic resistance. By changing the pressure or the velocity, we define the geometry of the deposited lines. Moreover, it is important to note that the photoresist viscosity influences R and substrate surface energy impacts θ , and therefore both parameters also play a significant role in the shape and size of the deposition. The roughness was measured on the profilometric data. As the surface is curved, a 2nd degree polynomial was fitted on a 10- μm wide region of the cross-section profile (Figure 3a). Residual data could then be calculated by subtracting the fit to the profile, onto which arithmetic average R_a , mean roughness depth R_z and root mean square R_q value could be extracted (Figure 3b). The values (R_a : 5.0 nm, R_q : 5.9 nm and R_z : 27.6 nm) confirm the low roughness of the surface. After light exposure and baking, we also confirmed the tight binding of SU-8 to glass and formed PDMS devices from the molds. We also fabricated wells and more complex designs to show the suitability of the process for rapid prototyping.

Conclusion

IDP is a simple process to form molds with round, smooth photoresist lines without the need for a clean room in resolution suitable for lab-on-

chip devices. We currently explore the method to build complex channel networks.

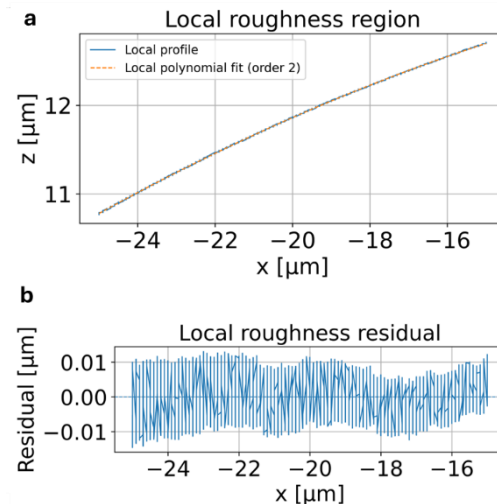


Figure 3: (a) Profilometer data (blue line) with 2nd degree polynomial fit (orange line) to detect curvature. (b) Residual data obtained by subtracting profile with 2nd degree polynomial.

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