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Novel methods to pattern polymers for microfluidics

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Abstract

We present two novel methods for the preparation of arbitrary micro-scale patterns of polymers on surfaces with pre-defined topography. While photosensitive polymers are used commonly together with optical lithography, the methods presented can be used for non-photostructurable polymers and where spin-coating cannot be performed. As demonstrator of the viability of the proposed fabrication process, they have been applied for the definition of hydrophobic barriers on a microfluidics network, which is dedicated to selectively dispense liquid to a spotting device consisting of 12 silicon microcantilevers.

Keywords: Liquid spotter, Microfluidics, Hidrophobic barriers, Soft-lithography, Ink-jet

1. Introduction

Microfluidics technology allows manipulating and transporting liquid at the micrometer scale by the suitable patterning of surfaces and by combining hydrophilic and hydrophobic areas [1]. Microfluidics technology can be based either on silicon-based technology (robust, reliable and highly developed) [2, 3] or on polymer-based technology (faster, more flexible and simple) [4, 5]. We present here the fabrication of a microfluidics network by the combination of silicon and polymer technologies. The network is dedicated to selectively supply liquid to a novel nanospotting device called Bioplume (Figure 1a) [6, 7].

Bioplume is an array of silicon microcantilevers that can deposit drops with suitable control of the position and the size and homogeneity of the drop. More properties of Bioplume deal with its parallel deposition (multiple depositions with a single load), its compatibility with different materials and a large range of feature size [8]. The fabricated Bioplume chip has 12 microcantilevers, 10 of them are dedicated to dispense liquid and the other two are piezoresistive cantilevers to allow alignment of the array with the substrate. Each cantilever incorporates a channel and a reservoir for liquid deposition and storage that is loaded by capillarity action.

An important challenge regarding the performance of the fluidic network relies in the fact that the cantilevers are very close one to the other. When they are dipped in the dispensing holes, the liquid overflows due to volume displacement causing cross-contamination between adjacent holes. The proposed solution to this issue is the fabrication of hydrophobic barriers between holes. These barriers will stop the liquid displaced while cantilevers are dipping and also will keep the liquid confined in the areas defined by them.

2. Fabrication of microfluidic chip

The fluidic network consists of 10 dispensing holes for the 10 depositing cantilevers plus two more holes for the alignment cantilevers. Each dispensing hole is 200 µm long, 100 µm wide and 525 µm deep, the separation between them being of 120 µm. Three reservoirs which allow easily pipetting supply the liquid to the dispensing holes. The channels drive selectively the liquids from the reservoirs to the dispensing holes.

For the fabrication of the microfluidic network standard silicon technology has been used. Starting with a double polished side silicon wafer, 30 nm of thermal SiO_2 is grown on both sides of the wafer and a 1 µm thick Al layer is deposited. A lithography step defines the reservoirs, channels and dispensing holes. Several reactive ion etching processes anisotropically etch subsequently the Al, the SiO_2 and 350 µm into silicon (using Bosch process) to define the channels. The design of the reservoirs and the dispensing holes are also patterned in the back side and they are dry etched until the through-wafer hole is defined. Finally the Aluminum and the oxide layers are removed by wet etching in HF, and the wafer is anodic bonded to a pyrex wafer (1000 V, 400ºC). Pyrex covers the dispensing holes, the channels and the reservoirs.

In Figure 1b and 1c the front and the back view of the silicon and pyrex microfluidic chip without the hydrophobic barriers are shown. The size of the chip is 20 mm wide and 12 mm long.

3. Fabrication of polymer hydrophobic barriers

In order to avoid liquid intermixing, polymer based barriers were defined between the dispensing holes. As the fabrication of the microfludics chip involves a final high temperature step (anodic bonding), definition of the polymer barriers is not possible during the fabrication process. It is also not possible to define them after the fabrication process by photolithography because the resist deposition by spinning would clog the channels avoiding the liquid flow. In consequence, we have explored two novel methods for polymer structuring, which are presented below.

3.1 Ink-jet printing

The first method is based on inkjet printing, which is a computer controlled drop-on-demand dispensing of microscale droplets by means of a piezoelectric actuated nozzle [9]. The sample is located in a motorized stage which movement defines the location where the droplets are dispensed. Here, we apply it as a flexible, direct-patterning and non-contact method to dispense five 50 µm sized polymer drops in between the openings of the microfluidic dispensing holes that result in a ~120 µm wide barrier. Figure 2a shows a drawing of the experimental set-up and a typical result of the deposition of 2 barriers formed by five drops each.

Inkjet printing is unique because of its flexibility for defining arbitrary patterns on surfaces and it cleanliness. The main challenge is to align de deposition with a pre-patterned surface, as in this case. The results of Figure 2b demonstrate that this alignment is possible. We are currently improving the system to allow the formation of longer patterns.

3.2 Soft-lithography

The second method is based on Micromolding in Capillaries (MIMIC) [10, 11]. This method relies on the use of a PDMS stamp. As it is shown in Figure 3, the channels in the PDMS stamp will be filled with a polymer resist by capillarity, which in turn will form the barriers.

The PDMS stamp is fabricated by soft lithographic techniques from a SU-8 master. After spin coating this resist on a bare silicon wafer and selectively expose it to UV-light, it is developed in PGMEA, obtaining the master for the PDMS stamps. The thickness of the SU-8 has been selected so as to be equal to the final height of the polymer barriers. Once the master is ready, pre-polymerized PDMS in a 1:10 ratio is poured on the master in order to replicate the complementary pattern. Finally the PDMS is thermally cured.

After alignment between the stamp and the microfluidic chip (see Figure 3), a drop of polymer, which in this case is a low viscosity epoxy-based resist developed for electron beam lithography [12], is placed at the beginning of the main channel and by capillarity action all the auxiliary channels (defining the barriers between holes) are filled. The polymer was exposed by UV-light (190 mJ/cm^2) and a post exposure bake was performed afterwards. The features that define the channels in the PDMS were 10 µm deep and 60 µm wide. We show in Figure 4 that the barriers made with the hydrophobic polymer are successfully defined, with a final height of 10 µm as measured with a mechanical profilometer. As the Figure 3d shows, it is a very clean process that avoids clogging the dispensing holes with hydrophobic polymer and makes very homogeneous barriers.

4. Validation test

We have tested the correct performance of the hydrophobic barriers fabricated by soft lithography. The reservoirs are filled with 2 DNA solution labelled with Cy3 and Cy5 fluorophores. Cy3 has green fluorescence and Cy5 has red fluorescence. Then the cantilevers are dipped in the reservoirs and matrices of spots are printed.

Figure 4a shows the results for a microfluidic chip without the hydrophobic barriers. Two of the reservoirs (at the edge) are filled with the Cy3 labelled DNA and the middle reservoir is filled with Cy5 labelled DNA. When the green light is filtered, clearly appears matrices of Cy5 dots in cantilevers of the edges where it was not supposed to be, and the same occurs when the red light is filtered and the middle cantilevers show its cross contamination. Figure 4b shows the same experiment but performed using a microfluidics chip with hydrophobic barriers. In this case, we observe a perfect correlation between reservoir loading and colour of the matrices, demonstrating that the hydrophobic barriers assures no cross contamination due to the volume of liquid displaced when the cantilevers are dipped in the dispensing holes.

5. Conclusions

Two novel methods have been described for the fabrication of the polymer hydrophobic barriers: ink-jet printing and soft lithography. Ink-jet printing allows high flexibility and a selective deposition of the polymer. Using soft-lithography, a better control of the barrier dimensions can be achieved. In addition, this technique is scalable, that is to say, barriers of

several heights can be achieved and high aspect ratio structures can be generated, which can be crucial for the optimum performance of the final device.

Finally, validation tests have been presented showing that the fabricated barriers avoid the cross-contamination and allows a completely selective deposition.

Acknowledgments

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Figure captions

Figure 1: (a) Array of silicon microcantilevers (Bioplume) just while performing the deposition of liquid drops. The separation between needles is of 120 µm. (b) Image of the back side of the fabricated microfluidic chip. Pyrex is covering the reservoirs, channels and dispensing holes. (c) Front side, the liquid can be easily pipetted to the reservoirs

Figure 2: (a) Scheme of the inkjet setup (b) and inkjet printed microdrops in between openings of the channels.

Figure 3: MIMIC process flow (a) A PDMS mould is aligned with the microfluidics network so the channels in the PDMS are placed between the dispensing holes. The reservoirs remain covered with PDMS to protect them from being filled by the polymer. (b) A drop of a low-viscosity and hydrophobic polymer is placed at the beginning of one of the PDMS channels. The channels are filled by capillary action. (c) After exposition and bake, the polymer is cured and the PDMS mould is removed. (d) Optical image demonstrating that the dispensing holes of the fluidic network have been successfully separated with the hydrophobic polymer barriers.

Figure 4: Validation test. The reservoirs are filled with 2 solutions labeled with Cy3 and Cy5 fluorophores, green fluorescence and red fluorescence respectively. The cantilevers are dipped inside the dispensing holes, causing the liquid overflow and matrices of spots are printed. (a) Corresponds to a microfluidic chip without the hydrophobic barriers. It can be seen that with a green filter there are Cy5 cross contamination and with a red filter also is proof that there is Cy3 cross contamination. (b) Corresponds to the same test on a microfluidic chip with hydrophobic barriers. The filtered images show no cross contamination between dispensing holes.

FIGURES:

Figure 1

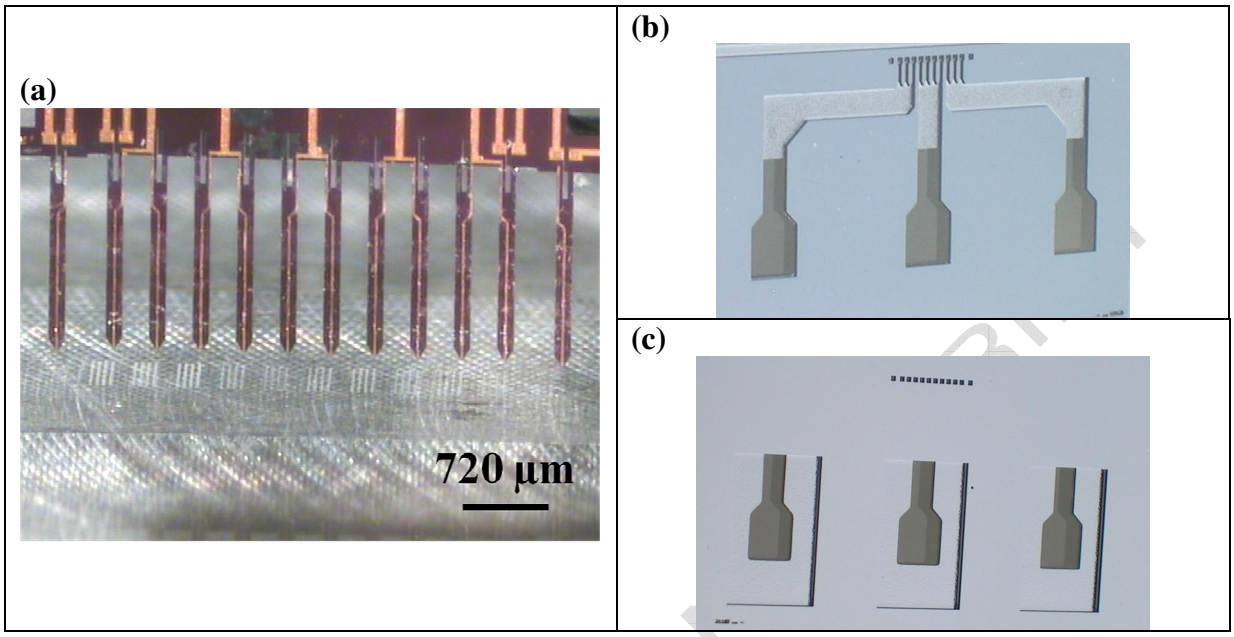

Figure 2

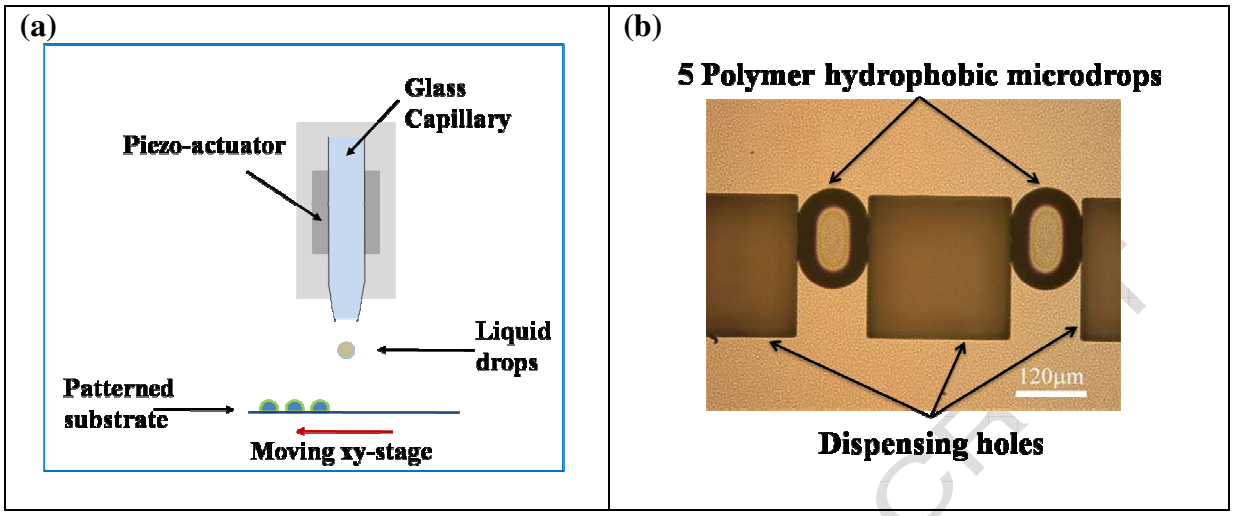

Figure 3

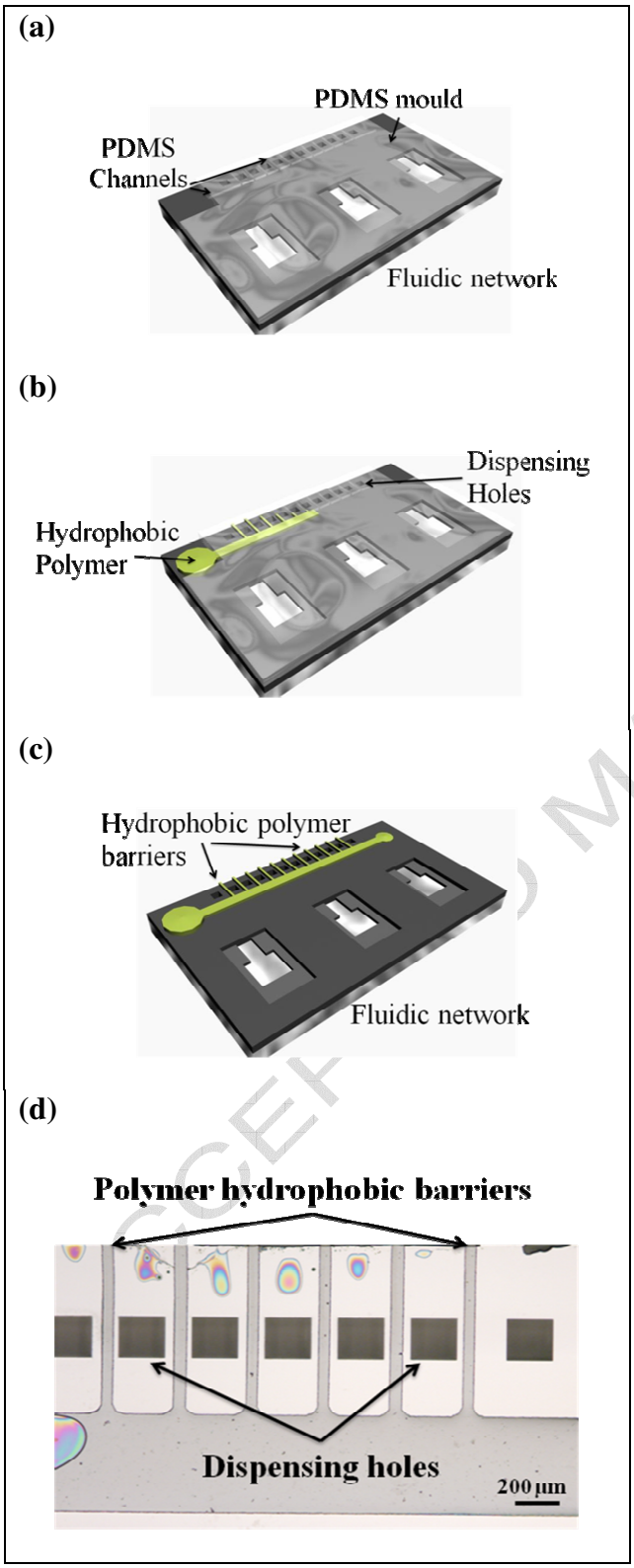

Figure 4