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Fabrication and characterization of injection molded multi level nano and microfluidic systems

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ABSTRACT

We here present a method for fabrication of multi-level all-polymer chips by means of silicon dry etching, electroplating and injection molding. This method was used for successful fabrication of microfluidic chips for applications in the fields of electrochemistry, cell trapping and DNA elongation. These chips incorporate channel depths in the range between 100 nm and 100 μm and depth to width aspect ratios between 1/200 and 2. Optimization of the sealing process of all-polymer COC microfluidic chips by means of thermal bonding is also presented. The latter includes comparing the bonding strength of UV-treated foils and presentation of a simple model for estimating the delamination pressure. With UV surface treatments, foils of 100 μm thickness were found to withstand pressures up to 9 atm in Ø4 mm cylindrical inlets when thermally bonded to micropatterned substrates of 2 mm thickness.

1. Introduction

For the fabrication of micro- and nano-machined systems for as Lab-on-chip (LoC) applications polymers are gaining at present more and more consideration over materials used for standard IC fabrication like Silicon and glass [1,2].

Polymer manufacturing is performed mostly by means of rapid prototyping methods such as polydimethylsiloxane (PDMS) casting, laser milling, or micromachining [3–5].

Although such fabrication methods are quite mature, they suffer from serious drawbacks when it comes to industrial production and cost efficiency. While the feasibility of more and more applications has been successfully demonstrated, only a few of the presented prototypes have reached the market. For large scale fabrication of polymer chips for Lab-on-Chip (LoC) applications, the most common methods for micro- and nanopatterning are LiGA (German acronym for Lithography, Electroplating and Molding) [6] or LiGA-like processes that involve, for example, the use of UV lithography [7]. In order to avoid the use of expensive synchrotron sources necessary for LiGA, obtain extremely flat and smooth sample surfaces and at the same time avoid the double inversion of stamp polarity [8], it is possible to carve the structures into the Si wafers in a so-called DEEMO (acronym for Dry Etching, Electroplating and Molding) process as first proposed by Elders et al. [9].

The procedure we here present is a variation of the DEEMO process performed using multiple and overlapped Si dry etching steps described in detail elsewhere [10]. This process enables high spatial resolution both in the width and the depth of the channels. The patterned Si wafers are then used to make nickel multi-level stamps (hereby referred to as shims) that are used for the fabrication of all-polymer chips by means of injection molding of Cyclic Olefin Copolymer (COC) 5013L10 from Topas™. Although a large number of polymers can be used for injection molding purposes, Topas is optimal when a material with low autofluorescence (for optical detection) and high chemical and thermal resistance are required.

Sealing of the devices was performed by thermal bonding with Topas foils of the same grade with thickness ranging from 100 μm to 2 mm. We focused on two methods based on previous works [11–14]: Plasma assisted and UV assisted thermal bonding. Of these, the UV bonding was superior and less time-consuming and is presented here. Data on the plasma method is given in Supplementary material S1.

The bonding procedure should be optimized for maximum bonding strength while still preserving the integrity of the channel geometry. We here report on such an optimization by applying the so-called razor blade test to measure the bonding strength [15], as this method can be applied while still maintaining the functionality of the device. In addition, we have deduced and experimentally verified that the crack length measured in the razor blade test can

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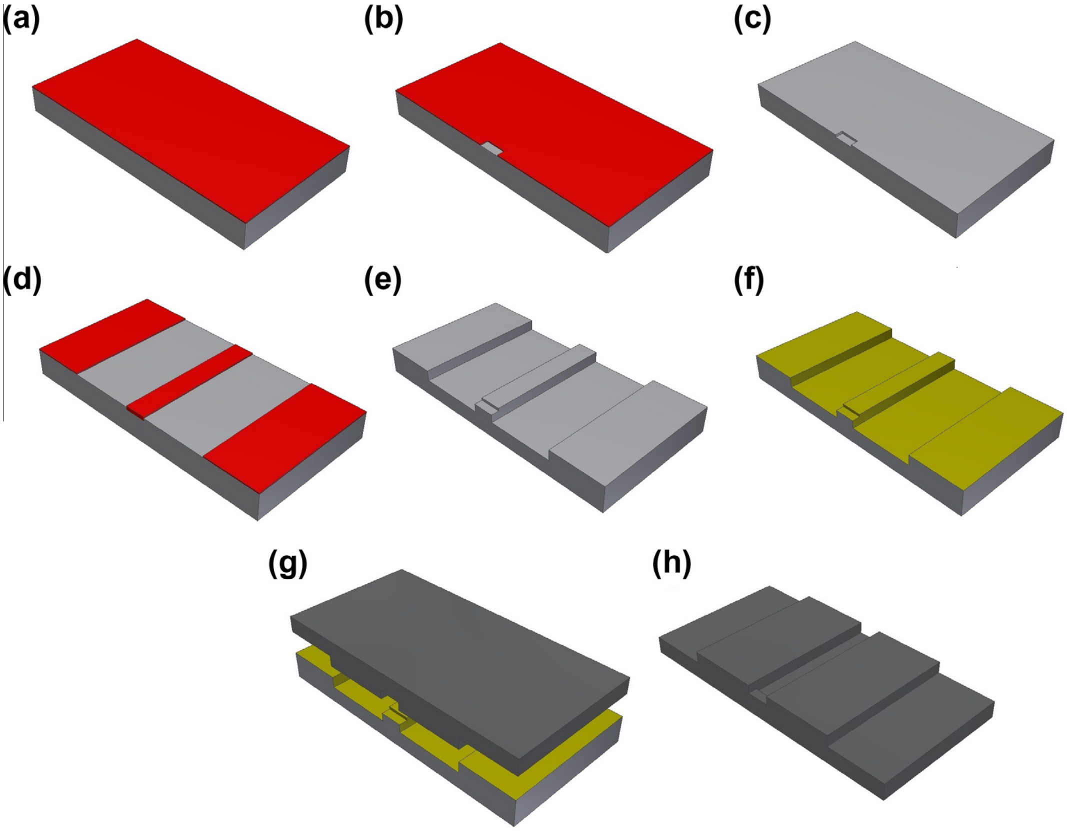

Fig. 1. Fabrication procedure for Ni shims: Spin coating (a), UV lithography (b), RIE etching of shallow channels and resist removal (c), spin coating and UV lithography (d), DRIE of Si for deep channels and resist removal (e), sputtering (f), Ni electroplating (g) and KOH etching of Si (h).

be directly related to the critical delamination pressure in a microfluidic channel by means of a simple model, see Supplementary material S2 for details. In this model, the delamination pressure in a circular inlet is given by:

$$P_{\max} = \frac{2E'\delta\tau^3}{a^2L^2} \tag{1}$$

where a is the inlet radius, τ the lid thickness, $E' = E/(1-\nu^2)$ E being Young's modulus and ν the Poisson ratio of the lid material, δ the blade thickness, and L the measured crack length.

Regarding the shim fabrication, we here describe a simplified version of a multi-level etching process presented in detail elsewhere [10].

The modified process is sketched in Fig. 1.

In respect to the one previously used, we here simplify the procedure by substituting an oxide etch mask with a spin coated resist layer of 2.2 μm thickness during both RIE and DRIE processing. The use of a resist mask was made possible by using only the modified BOSCH process described in [10]. As in previous work [10], the shim thickess was tuned to be around 300 μm. Using this process, chips equipped with luer fittings were injection molded with an ENGEL Victory 80/45 with a maximum clamping force of 450 Tons. Mold temperatures between 110 and 130 °C as well as an injection pressure of 1700 Bars were used for sample molding. Samples having features ranging in width from 5 to 50 μm and in depth between 100 nm and 50 μm and with aspect ratios as low as 1/200 without channel collapse. The cycle times of the injection molding were noticeably reduced compared to the process described in [10] to about 1 min by inserting a system for localized heating and cooling of the sample area.

For the bonding, commercially available TOPAS 5013L10 foils (T_g = 134 °C) of thickness between 100 and 500 μm purchased from TOPAS Advanced Polymers GmbH were used as sealing lids. The foils are obtained by extrusion of the same material provided for injection molding. All bonding experiments here described were performed with 100 μm thick foils. Such thickness was chosen because a large number of bio-applications use thin lids in order to have small working distances and allow on-chip optical detection. To test also the bonding of thicker substrates, 2 mm thick flat disks, similar to the patterned ones were injection molded to be used as sealing lids. An example of a bonded chip is shown in Fig. 2. Before thermal bonding, the surfaces of both the foil and the 2 mm thick sample were exposed to a UV lamp (DYMAX mercury UV-bulb F/5000) emitting over the full unfiltered Hg line spectrum with a power of 44.5 W/cm^2 measured at the wavelength 365 nm. All samples were kept under the UV light for 30 s.

After bonding samples at temperatures between 110 and 125 °C, we concluded that at higher temperatures the main issue is the partial filling of the channels with lower aspect ratios. In particular, at T = 125 °C it was not possible to separate the thin 100 μm thick folis from the 2 mm thick substrates. For this reason we kept a maximum bonding temperature of 120 °C.

Bonding (further details in Supplementary material S3) was therefore performed applying forces between 2 and 15 kN at temperatures of 115 and 120 °C. In order to assess the influence of bonding time, samples were bonded at 115 °C for both 5 min and 10 min. The razor blade test was then performed as shown in Fig. 3. To obtain the crack length L the horizontal projection of the blade slope L' was added to the distance L_0 between the blade tip and the last fringe. The blades used (Millarco) were of rectangular shape 39.5 × 20 mm. After the measurement of the crack length, a measurement of the delamination pressure was performed on the same samples by inserting a liquid dye into the microchannels and then applying pressure until delamination