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MICROFLUIDIC MANIFOLDS BY POLYMER HOT EMBOSSING FOR μ-TAS APPLICATIONS

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Abstract:

In this paper we present a low-cost replication method for planar microstructures based on polymer substrates. Several microfluidic chips for capillary electrophoresis (CE) applications with a range of channel widths between 0.8 μm and 100 μm have been produced by this method, yielding a very good structural replication and short production times.

Keywords: polymer microfabrication, hot embossing, capillary electrophoresis chips

1. Introduction

In the past microfluidic devices for miniaturized chemical analysis systems (μ-TAS) [1] have been fabricated almost exclusively in silicon, glass or quartz [2], mainly for the reason that microfabrication methods for these materials have been extensively developed for the microelectronics industry. For many applications (for an overview see e.g. [3,4]) however, these materials and the associated production methods are either too expensive for a commercial product or the material properties induce particular problems like protein sticking to silicon surfaces. The alternative lies in the use of polymers as the chip material, offering a wide range of physical and chemical material parameters at generally very little cost and low-cost replication methods for polymer microfabrication. Several devices were reported recently in the literature, fabricated on different polymer substrates using either laser ablation [5], injection moulding [6], silicone rubber casting [7] or embossing [8] as a microfabrication method for the microchannel formation. We have used hot embossing to fabricate devices in polymers like polymethylmetacrylate (PMMA) and polycarbonate (PC). Hot embossing offers the advantage of low costs for embossing tools, a simple replication process and high structural accuracy and is therefore suited for a wide range of microfluidic applications from rapid prototyping to high-volume mass fabrication.

2. Fabrication Process and Instrumentation

The complete fabrication process for the devices can be seen in Fig. 1. After designing the mask with the desired structures, the embossing master is fabricated. This can be realized in a variety of techniques; for large structures (>100 μm), traditional CNC-machining of materials like stainless steel is often accurate enough, particularly if no sharp corners or right angles are needed. For smaller feature sizes, electroplating of a wet or dry etched silicon structure (e.g. the DEEMO-process [9]) or of a thick photoresist structure with a galvanic starting yields a metal tool, usually nickel or nickel-cobalt. For very small structures with high aspect ratios, LIGA [10] or laser-LIGA in thick resists (like EPON SU-8) are suitable technologies to obtain the embossing master.

In the embossing machine, the embossing tool and the polymer substrate are heated separately under vacuum (extends the lifetime of the master) to a temperature just above the glass transition temperature T_g of the polymer material. The tool is then brought into contact with the substrate and embossed with a controlled force, typically of the order of several kN for several seconds. Still applying the embossing force, the tool-substrate sandwich is then cooled to just below T_g.
To minimize thermally induced stresses as well as replication errors due to the different thermal expansion coefficients of tool and substrate, this thermal cycle should be as small as possible, in our case currently 40°C, but can reduced to as little as 25°C. After reaching the lower cycle temperature, the embossing tool is mechanically separated from the substrate which now contains the desired features. It now can be processed further, e.g. by drilling holes or bonding it to a cover lid to close the channels. The complete process cycle time in our experimental setup is of the order of 9 minutes but can be reduced to about 5 minutes without major machine modifications. The experiments were carried out on commercially available hot embossing instruments.

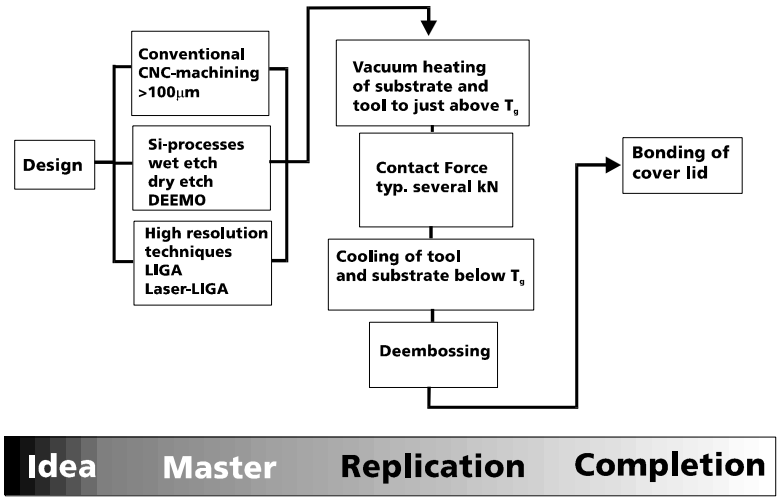

Fig. 1. Schematics of the fabrication process.

3. Results

The first device fabricated is a planar chip for two-dimensional capillary electrophoresis, utilizing an embossing tool fabricated from a <100>-silicon wafer using an advanced silicon etch (ASE) process in an induction-coupled plasma (ICP) reactor (Fig.2). It uses a layout previously reported [11] for a quartz device with overall dimensions of 23 × 23 mm.

It has a fluidic channel in the first separation dimension of a width of 80 µm and depth

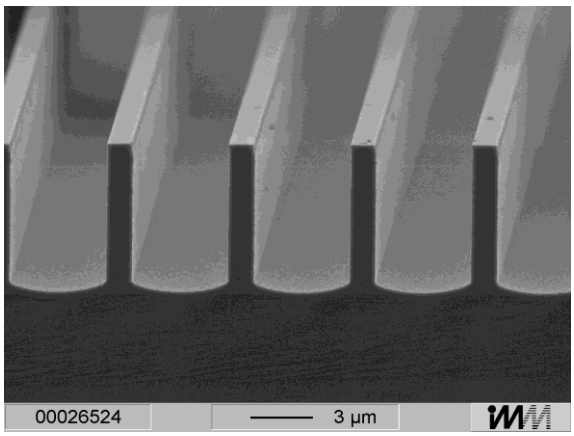

Fig.2: Embossing tool fabricated in silicon with ASE.

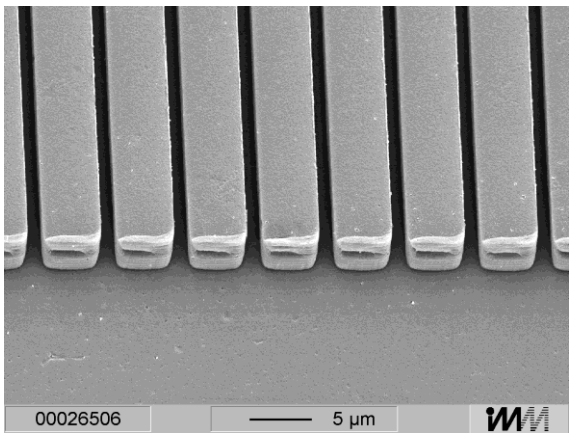

Fig.3: Resulting channel structure.

5-8 μm (lower part of Fig. 3), the second separation dimension consists of an array of 500 channels with a width of 800 nm and a depth of 5-8 μm (upper part of Fig.3). The embossing temperatures were in the region between 155°C and 165°C in case of PMMA and 150°C in case of PC. After deembossing, a very good replication of the structure with an aspect ratio of up to 10 could be observed, as shown in Fig.3.

Another CE-structure was fabricated using a full 4" wet etched silicon wafer electroplated with a Ti/W/Ni top layer. Figure 4 shows the channel crossing in the injection area. The typical wall angle from the Si wet etch can be seen easily. Structures with inclined walls are particularly easy to emboss as during deembossing only very low frictional forces occur.

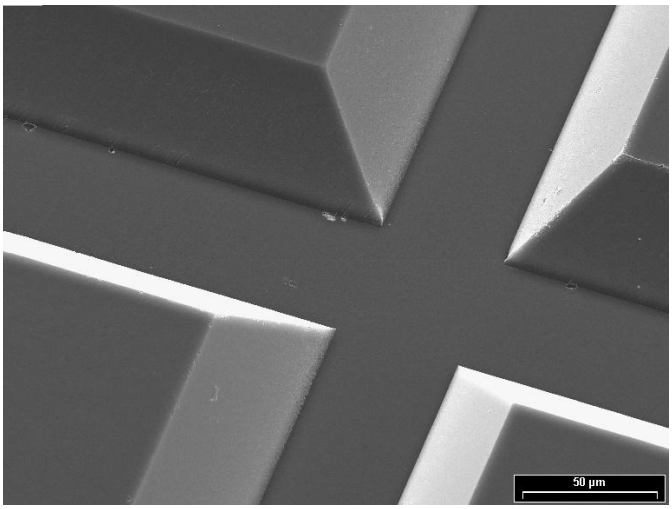

Fig. 4: Channels from electroplated wet etched silicon.

The third device is a channel structure for capillary electrophoresis with a channel cross-section of 100 × 40 μm. For this device the embossing tool was fabricated by electroplating nickel onto a photolithographically patterned resist structure. The embossing parameters were 130°C for 4 minutes and 150°C for 5 minutes for PMMA and PC respectively. As an example of the resulting structures, a channel intersection is shown in Fig. 5. The smooth and vertical walls which can be accomplished with this method can clearly be seen. Deembossing of these structures is more critical than in the case of structures with inclined walls and slight deformations on the channel edge (typical size between 1 and 2 μm) can be observed due to the frictional forces. To complete the device, the channels were closed with a PMMA-lid by a chemically assisted bonding method, yielding a cross-sectional accuracy of 5%. The good quality of the bond can be seen in Fig.6, where the chip was first frozen in liquid nitrogen and the broken across a channel. No interface between the two bonded PMMA plates can be observed.

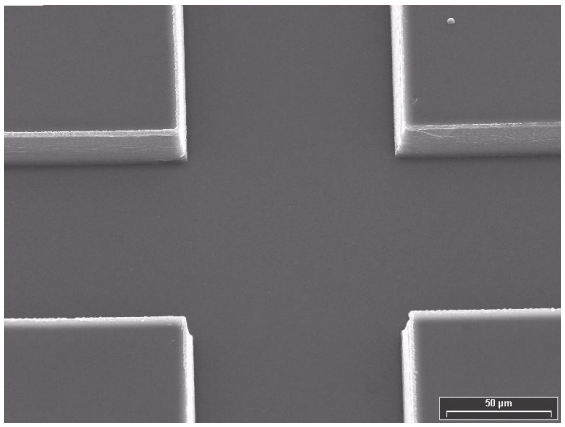

Fig. 5: Channels produced with a Ni-master.

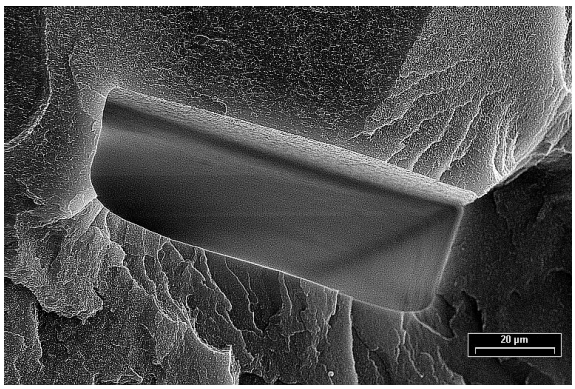

Fig. 6: Cross-section of a channel with a bonded cover lid. Note the absence of a visible interface between channel plate and cover plate.

Conclusions

We have fabricated several microfluidic devices for CE-applications by means of hot embossing of polymer substrates. The results indicate that this method is well suited for the production of planar polymer microstructures from rapid prototyping (low tool costs and few process steps) to high volume production. Further work will concentrate on the extension of the material range (e.g. towards high T_g materials like PEEK, metals, glass and ceramics), the shortening of the complete process cycle and the optimization of the process parameters particularly to minimize stresses during the embossing and in the deembossing stage.

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