COMBINED PHOTOLITHOGRAPHY AND EMBOSsing FOR FABRICATION OF MULTILEVEL, FREE STANDING MICROFLUIDIC STRUCTURES

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ABSTRACT
We present fabrication of microfluidic structures by using a combined photolithography and UV-embossing process. The mask/master is made on a glass wafer. An aluminum pattern defines areas to be lithographically patterned, and embossed structures are defined by two-level SU-8 structures. The aluminum pattern will define a sharp tip at the edge while embossing results in fluidic structures. UV-sensitive inorganic-organic hybrid polymer, ORMOCER, is used as chip material. ORMOCER is spun on a transparency which makes stamp detachment and release easy. UV-exposure of the Al/SU-8/SU-8 mask/master simultaneously forms the desired structures in a single step.

KEYWORDS: ORMOCER, UV-embossing, lithography, microfluidics

INTRODUCTION
Photolithography and UV-embossing have previously been combined in the fabrication of devices where both nano and micro sized structures are needed [1]. This process is called combined nanoimprint and photolithography (CNP). In CNP process different types of mask-master designs can be used depending on the desired structures. One of the most common problems in nanoimprint is the residual layer that remains after imprinting. The CNP process was developed to overtake this problem by using a stamp where a light-blocking metal layer is placed on top of the mold protrusions [1]. In this study, this idea is applied to the fabrication of a microfluidic chip. Aluminum and SU-8 are used to form the composite mask/stamp on a glass substrate. This stamp is used to fabricate microfluidic chip into a photosensitive inorganic-organic hybrid, ORMOCER. ORMOCER combines the surface properties of glass and easy processing of polymers which makes it an attractive material for microfluidic structures [2]. In our previous study we have demonstrated the excellent properties of ORMOCER as a material for capillary electrophoresis (CE) [3].

EXPERIMENTAL
The mask/stamp is fabricated on top of the 100 mm in diameter Pyrex wafer. The wafer is RCA-1 cleaned prior processing. A 200 nm thick aluminum layer is deposited on top of the substrate by sputtering (Oxford, Plasmalab System 400). Standard UV-lithography is used to pattern the aluminum. Next, the aluminum is etched with phosphoric acid etching mixture at 50°C, rinsed and dried, after which the resist is removed in acetone. The wafer is then baked in the oven at 120 °C for at least an hour to remove all the moisture from the wafer. The baking step will enhance the adhesion between the SU-8 and the substrate. SU-8 3050 (MicroChem) is then spin coated on top of the Pyrex wafer with the spin speed of 3000 rpm, resulting a layer thickness of 50 μm. This layer will define the height of the channel structures (see Figure 1a). The SU-8 is soft baked on a hot plate at 65 °C for 5 min, after which the temperature is ramped to 95 °C and baked for 15 min. The wafer is let to cool down below 50 °C. The exposure is done with SÜSS MA-6 mask aligner. Exposure dose of 400 mJ/cm² is used. The post exposure bake is done on a hot plate at 95 °C for 15 min and the wafer is let to cool down to room temperature. The second layer of SU-8 is spun with the spin speed of 9000 rpm resulting to layer thickness of 20 μm. This layer will define the thickness of the bottom of the structures together with the residual layer. The soft bake is done on a hot plate at 65 °C for 5 min, followed by 8 minutes bake at 95 °C. Exposure through the third photomask is done with exposure dose of about 200 mJ/cm². The post exposure bake is done at 95 °C for 8 min. After cooling, the development of the both layers is done with 1-Methoxy-2-propyl acetate (PGMEA). Finally the stamp is coated with Teflon like fluoropolymer by using reactive ion etching (RIE, Oxford Plasmalab 80 plus) machine. The deposition parameters are; power 50 W, pressure 250 mTorr, CHF3 flow 100 sccm and time 5 min. The thickness of the fluoropolymer coating is estimated to be about 8 nm. A cross sectional schematics of the stamp is presented in Figure 1a and the photograph of the finished stamp is shown in Figure 1b.

A commercially available inorganic-organic hybrid material, ORMOCER (ORMOCOMP US-S4, Micro Resist Technology, GmbH, Darmstadt, Germany), is spun on top of the overhead transparency (attached to a carrier wafer with double sided tape) with the spin speed of 1000 rpm for 30 s. A two minutes soft bake is done to remove the air bubbles, after which the embossing is done by using a wafer bonder (AWB-04, AML). The force of 500 N is used for 10 minutes to emboss the structures under vacuum. After embossing, the wafer-stamp stack is moved to a mask aligner where exposure through the mask/stamp is done. After exposure, the mask/stamp is easily detached and the structures can be developed. The structures can then be detached from the transparency.
RESULTS AND DISCUSSION

The glass is chosen as a substrate for the stamp since transparent material is needed to enable the exposure through the stamp. SU-8 3050 is used since it has better adhesion to glass and aluminum compared to other types of SU-8 (such as SU-8 50). The aluminum layer will block the UV-light on selected areas, defining the edges of the fluidic chip. The glass-SU-8 hybrid stamp is quite rigid and for that reason the detachment of the stamp might be a problem even when the anti-adhesion layer is used. Here, however since the ORMOCER is spin coated on top of the flexible transparency, the detachment is easy. Another possibility would be the use of polydimethylsiloxane (PDMS) as a stamp since it also offers the needed UV-transparency. PDMS is, however, difficult to metallize and in addition it is so flexible that the structures are easily deformed during embossing.

One of the most important parameters in the process is the exposure time. In a typical embossing process the UV-exposure dose is not critical since the pattern resolution is defined by the stamp structures. But here, on the other hand, since the composite stamp is used the exposure time becomes as critical as in the normal optical lithography where chromium mask is used. Two levels of SU-8 structures on the stamp are needed since free standing structures are to be made. The residual layer, by itself, is not thick enough to support the bottom of the microchannel and for that reason, an additional 20 μm SU-8 layer is spin coated on the stamp. The ORMOCER channel thickness is about 46 μm measured with the profilometer (vs. design value of 50 μm). In Figure 2a a SEM micrograph of the two-level SU-8 stamp is shown and in Figure 2b an embossed ORMOCER channel is presented. The channel edges are somewhat rounded in the embossing process. This is due to inadequate filling of the stamp structures which is many time a problem when large volumes have to be filled. The profile could be further improved by optimizing the imprinting parameters and this will be part of our future studies. The rounded profile will not however cause problems in the operation of the fluidic chip.

ORMOCER structures can be enclosed by adhesive bonding as presented previously [2]. The bonded ORMOCER channel is shown in Figure 3a. Because ORMOCER is spin coated on top of the transparency, where the adhesion of ORMOCER is not good, the free-standing structures are easily made by detaching the structures with a sharp knife. The free standing ORMOCER microfluidic chip is presented in Figure 3b. The ORMOCER microfluidic channels fill easily
by capillary forces due to a relatively low contact angle of ORMOCER (contact angle about 60°). ORMOCER channels also maintain electro osmotic flow which makes the electrophoretic separation possible.

CONCLUSION

The fabrication method presented here provides a fast and simple method for microfluidic chip fabrication. Just one UV-exposure is needed to define all the elements of a fluidic chip. Fabrication of the two-level composite mask/stamp, however, requires considerable processing. Aluminum is used to define the edges and the sharp tips in the microfluidic chip and the thick SU-8 structures for the formation of the channels. The stamp is used to fabricate microfluidic structures on inorganic-organic hybrid polymer, ORMOCER. In order to have a free-standing chip thickness of any value, the two-layer stamp is used, while relying on the thin residual layer thickness would be suitable for non-released structures only. ORMOCER has been shown in previous studies to be an interesting material for microfluidic chips, especially for proteomics applications due to its non-fouling surface properties.

ACKNOWLEDGEMENTS

The work was financially supported by the Graduate School of Electrical and Communication Engineering at Aalto University.

REFERENCES


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