FAST PROTOTYPING OF µTAS BY DIRECT LASER WRITING

V. J. Cadarso[1], K. Pfeiffer[2], U. Ostrzinski[2], A. Voigt[2], G. Gruetzner[2] and J. Brugger[1]
[1]*Microsystems Laboratory, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland*
[2]*Micro resist technology GmbH, Germany*

ABSTRACT

In this work the combined use of direct laser writing (DWL) and a new epoxy material (mr-DWL) for fast prototyping of µTAS devices is demonstrated. The fabrication process is based in the use of DWL to manufacture epoxy-based masters without using any mask, and replicate them into PDMS. A total processing time of less than 12h from the design to the final working µTAS is demonstrated. Two different PDMS microfluidic structures are fabricated and tested as proof of concept of the good performance of the proposed technology.

KEYWORDS: µTAS fast prototyping, epoxy material, direct write laser, PDMS

INTRODUCTION

Nowadays, µTAS are present in a myriad of chemistry, bio-chemistry and life sciences applications. However, such devices usually require cm-scale areas containing micrometric structures that must be cost-efficiently fabricated. One of the most used materials to fulfill these requirements is the polydimethylsiloxane (PDMS) elastomer, which permits fast prototyping [1-3]. Typically, a master for casting PDMS is first fabricated with conventional microfabrication techniques. One of the most common methods to develop µTAS is based on the replication of PDMS structures from a SU-8 master [4]. However, the fabrication of such master implies the manufacture of photolithography masks, which normally is expensive and time consuming. Furthermore, an optimization investigating several design variations of the µTAS is usually required, involving the fabrication of further masks and consequently increasing the processing time and cost. Thus there is a continued interest in alternative, low-cost, fast, microfabrication methods to develop such masters. In this work a method to perform fast prototyping of µTAS without using any photolithography mask is presented. Direct laser writing (DWL) of a new epoxy material [5] is proposed in this work to directly cost-efficiently prototype such masters.

EXPERIMENTAL

The master fabrication process is depicted in Figure 1. Initially, a negative tone epoxy resist very similar to SU-8 but optimized to be sensitive at the exposure wavelength of 405 nm (mr-DWL, micro resist technology GmbH, Germany) is spin coated over a silicon wafer and prebaked at 90ºC for 30 min. After the prebake, a commercial DWL-tool (DWL200, Heidelberg Instruments GmbH, Germany) is used to directly expose the epoxy material (Figure 1A). DWL is an optical pattern generator based on a fast acusto-optical laser scanner. This scan exposure is done automatically in a time between 30 min to 1h30 depending on the density of structures in the wafer. A diode laser tuned with an output power of 66 mW was used as a continuous light source. The system can be equipped with different objective lenses resulting in different optical resolutions. The light was focused onto the polymeric layer using an objective lens with 4 mm focal length and an optical resolution of 0.7 µm. Immediately after the exposure, a post-exposure bake at 90ºC for 30 min was performed to induce the cross-linking of the exposed areas. Then, the structures can be relaxed at room temperature for 24h to reduce the internal stresses prior to their development in propylene glycol methyl ether acetate (PGMEA) to remove the mr-DWL that was not exposed (Figure 1B). Finally, a hard-bake (HB) can be done to reduce the ageing of the fabricated devices [6].

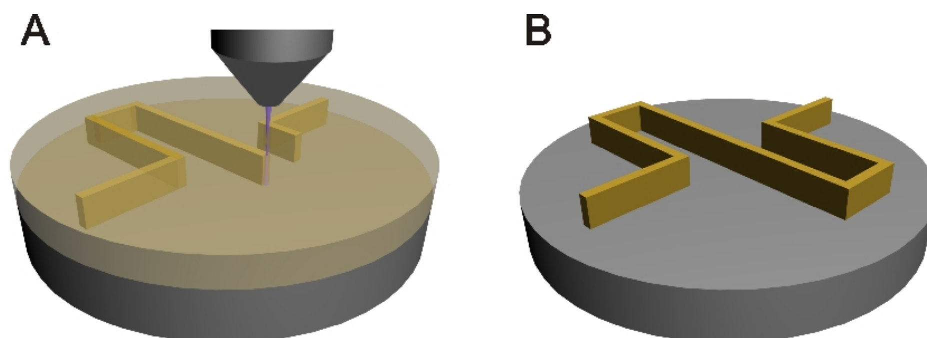

Figure 1: (A) DWL scan exposure of the spin coated mr-DWL epoxy material.
(B) After cross-linking and development the master is ready to be used.

Once the master is completed, it is possible to replicate it into PDMS by cast molding and bond the PDMS microstructures into a glass substrate to achieve the final devices. The total time to complete the µTAS prototype fabrication from the design to the final working device is less than 48h. Furthermore, if the fabricated masters do not require long term stability the relaxation time and the HB steps can be omitted resulting in a total process time of less than 12h, of

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which approximately only less than 4h are of active manufacturing. This short processing time, without requiring any photolithographic mask, allows fast prototyping of µTAS.

RESULTS AND DISCUSSION

DWL has been used to fabricate test structures in order to validate its capabilities. Figure 2 shows three masters fabricated using this method: Fig. 2A shows two high aspect ratio epoxy structures 35µm-thick 4 and 5µm-width, respectively. Figure 2B shows dense lines 6 and 7µm-width spaced the same distance and Figure 2C shows dense 35µm-deep trenches. All the fabricated structures exhibit vertical sidewalls and low roughness.

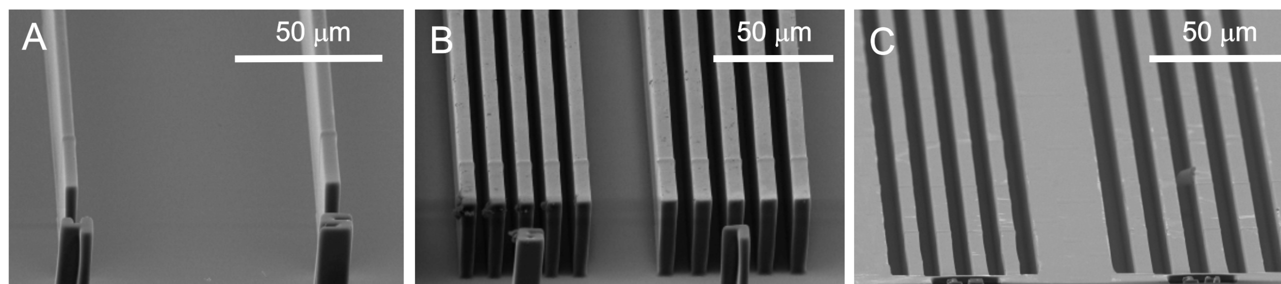

Figure 2: SEM pictures of 35µm-thickness epoxy structures fabricated by DWL: (A) High aspect ratio isolated structures, (B) dense line structures and (C) deep dense trenches.

In order to validate the use of the DWL epoxy structures in a PDMS replication process two different microfluidic systems have been fabricated using masters prepared with the DWL write method described above and subsequently replicated. Figure 3 shows a original mr-DWL master (A) and the replicated PDMS negative structure (B). The 100µm-side triangular holes originally fabricated in the epoxy material are accurately replicated as triangular columns, showing the same thickness as the surrounding sealing PDMS structure. Replication of this structure was done without any additional anti-sticking layer. However, the final PDMS structures exhibit high fidelity to the original design and no defects or residues could be observed in the master after completing the replication process. Figure 3C shows an optical image of the same PDMS structure exhibiting a micro-channel 200µm-wide connected to a region filled with the triangular micro pillars. Conversely, Figure 3D present an array of serpentine-like micro-channels 30µm wide that is designed as a micromixer. Fluidic microchannels in both structures are 80µm deep.

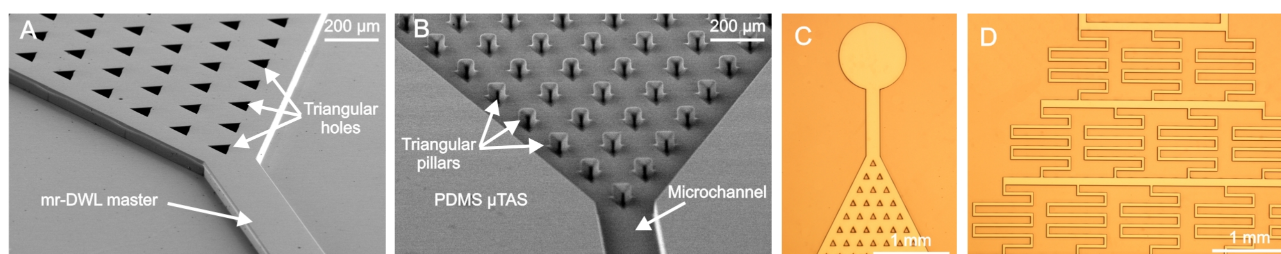

Figure 3: SEM images of (A) a mr-DWL master exhibiting a bulk structure with 100µm-side triangular holes and (B) its PDMS negative replica showing triangular pillars with the same thickness as the microchannels depth. (C) Optical microscope image of the same PDMS microfluidic component and (D) an array of 30µm-wide serpentine-like channels.

To validate the proposed technology both micro-fluidic structures were bonded onto a glass substrate and filled using an active external pump with a constant flux rate of 5 µl/min. Figure 4A shows a picture of the filter structure bonded to the glass. The structure was filled and emptied repeated times with water to test its adhesion to the glass. Some residues of water can be observed in the bottom corners. Figure 4B shows the filter filled with a water solution blue ink, in order to increase the contrast between the microchannels and the PDMS structures. No leakage can be observed in the triangular pillars regions, proving the good adhesion to the substrate and that their thickness is equivalent to the rest of the PDMS structures. Figure 4C shows the micromixer device bonded to the glass substrate and with both inputs connected to an active pump, prior to be filled. Figure 4D shows the same device once water-based blue and red inks are injected at the same flux rate in input 1 and 2 respectively. As can be observed, the blue ink fills the left side channels, while the red ink fills the right side ones. In the middle region both inks joins together and are consequently mixed. No leakage can be observed during this process. Both PDMS µTAS components where replicated from epoxy masters fabricated using DWL without the relaxation time and the HB steps and without using any anti-sticking layer. The total processing time from the already existing design to the final structures was of approximately 11h for 2 wafers and a total of 42 devices, of which 15 were bonded to glass substrate and tested. From this step it would be possible to optimize the design and fast prototype new devices, fabricate a final master mould using the same technique without using a photolithographic mask or fabricate a mask with the optimal designs if high throughput fabrication of master is required.

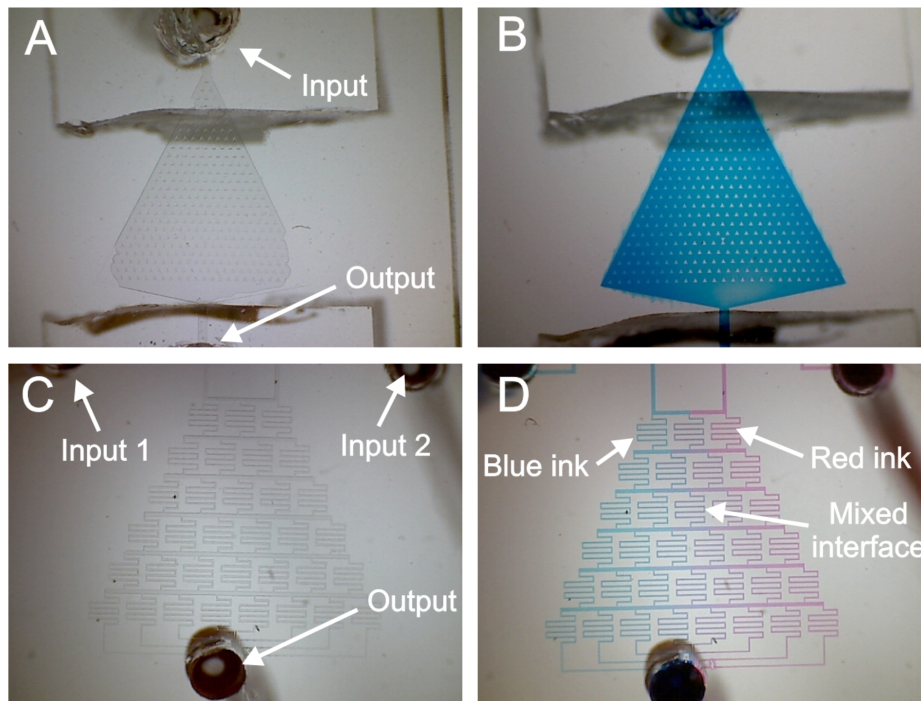

Figure 4:Optical pictures of two PDMS µTAS components bonded to a glass substrate: first a filter structure exhibiting triangular columns (A) before and (B) after filling it with a blue ink solution and second, a micromixer (C) as bonded to the glass substrate and (D) after injecting a blue and a red inks in inputs 1 and 2, respectively.

CONCLUSION

Epoxy structures with high aspect ratio, vertical walls and low roughness for both positive and negative designs have been fabricated using a commercial DWL tool. Such tools are more and more available in the microfabrication laboratories due to the development of compact systems with low-cost lasers. Two different µTAS components have been fabricated by replication of the mr-DWL structures into PDMS. We have demonstrated that the full fabrication process can be done in less 12h if no long term stability is required, and less than 48h are required for masters planned to be replicated several times. This, together with the good performance of the fabricated structures, demonstrates that DWL is a fast and cost-efficient method to fabricate temporal and long term use epoxy masters allowing fast prototyping of µTAS.

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CONTACT

*V.J. Cadarso and J. Brugger, Microsystems laboratory, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 17, 1020 Lausanne, Switzerland. victor.cadarso@epfl.ch, juergen.brugger@epfl.ch.