Abstract — This paper will show the realization of micro structures in polymeric materials including the preparation of high precision embossing masters. For embossing a two-depth silicon master tool was developed, that is known as 2.5 dimensional pattern. Goal of the investigation and reason for the second depth was the implementation of a special welding structure and the realization of smallest possible join formation between polymer substrates. After the Si master tool was realized the micro structures were molded to a so called soft working stamp. Using this stamp the patterns were transferred to a polymeric substrate under accompanying characterization and measurement. At least the channel like structures should be covered by another polymer. Therefore a laser transmission welding process was developed. With an additional absorbing layer two transparent substrates were welded by an infrared laser. Finally the strength of the bonding interface was characterized by a micro chevron pull test.

Keywords: Hot embossing, Imprinting, Laser transmission welding, 2.5 dimensional patterning, micro fluidics.

I - Introduction

Low cost micro fluidic applications require polymer materials and suitable technologies to work with these polymers. While high precision silicon micro technologies are well developed and often commercialized today, the micro machining processes for non silicon materials are still under development. Especially the smallest possible feature size for joining sensitive structures is not satisfying today. Especially if small and narrow structures are needed laser micromachining cannot fulfill these requirements. Here an imprint technology like polymer hot embossing could be an alternative. The origin of the high precision structures is a micro machined Silicon master tool, realized with UV lithography and deep reactive ion etching (DRIE) processes. The smallest possible feature size therefore is around 1 µm. Next to direct embossing the Silicon master could be used for the realization of a soft working stamp which is further used for the following hot embossing process.

II - Experimental Details

A. Silicon Master and Working Stamp Development

A test layout with smallest structures around 5 µm was designed and manufactured to investigate the transfer accuracy of molding and hot embossing within two steps. For laser welding an additionally second level of structures was integrated, giving material for melting like a sacrificial layer. That means a first structure was used for functional structures like fluidic channels and the second step was used for supporting the laser welding process realizing the contact area and limiting the melting zone (Fig. 1). It shows the first lithography step using a positive resist and a DRIE step with 5 µm or 10 µm depths for the supporting structure.

![Figure 1: Schematically view of the 2.5 D layout of the Si master tool](image)

Afterwards a spray coated resist was used to realize the second step of structuring with depths around 50 µm. The width of the channels as well as the supporting structures was varying between 20 µm and 80 µm or 5 µm and 20 µm on top, respectively. The characterization and measurement of the structures showed a high degree of homogeneity and form the basis for the validation of the pattern transfer using hot embossing [1]. After the Si master tool was realized the micro structures were molded to a so called soft working stamp.

For the working stamp fabrication 6 inch sized and 3 mm thick borosilicate glass wafers were used as back plane. These wafers were used as delivered without any pre-treatment. First the wafers were baked at 200 °C for 15 minutes in a furnace or a hot plate to remove the moisture of the substrates. After that an adhesion promoter (Shin-Etsu, Tokyo, Japan) was deposited with the spin coater RC8 (SUSS MicroTec, Garching, Germany). This step was followed by a hard bake at 180 °C for 5 minutes on a hot plate. In parallel to that the...

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silicon master wafer containing the original and precise patterns must be pre-treated to ensure the demolding of the polymer working stamp. Therefore an anti-sticking layer was deposited onto the silicon surface. After that the master wafer was stored for 24 hours at room temperature to ensure the full anti-sticking effect.

The used forming polymer consists of the perfluoroalkylpolyether (PFPE) Fluorolink® MD500 (Solvay Solexis, Brussel, Belgium) and 1-2 % of the photo initiator DURACOUR. This photo sensitive forming polymer was coated onto the pre-treated silicon master and the glass backplane including the adhesion promoter was inserted. Then, the stack was cured with UV light for 20 minutes and demolded manually (for comparison see Figure 2).

The glass transition point of the PMMA slides is around 100 °C and the process temperature was adjusted from 130 °C to 160 °C. The pressure of the embossing process was defined to 7.5 kN for 6 inch area and the duration of the embossing process was set to 30 min. After cooling down under pressure the working stamp had to be demolded manually from the PMMA substrate. This process is a critical step and depends on the kind, depth and amount of the structures. The successful process results in structured PMMA material and shows a high dimensional accuracy regarding duplication precision. Here the range of tolerance was between 3 % and 5 %. Additionally to profilometry the imprints were characterized by SEM (see Figure 5).

This replication technology allows the fabrication of soft working stamps with dimensions ranging from µm down to nm and covers requirements from both hot embossing and nano imprint lithography [2]. This was demonstrated with structures in the µm range for hot embossing (see Figure 3). The dimensional accuracy of the hot embossing working stamps according to the silicon masters was determined with profilometry and shows a high reproducibility. Here the accuracy was measured in a range of about 2 % to 2.5 % tolerance.

For hot embossing 6 inch 1 mm thick polymethylmethacrylate (PMMA) wafers (type: 99524 by Rohm/Degussa now Evonik, Brehna, Germany) were used. By using soft working stamps hot embossing was performed in a 540 HE substrate bonder (EVG, Figure 4) under defined pressure and temperature conditions.

B. Pattern transfer by hot embossing

The used forming polymer consists of the perfluoroalkylpolyether (PFPE) Fluorolink® MD500 (Solvay Solexis, Brussel, Belgium) and 1-2 % of the photo initiator DURACOUR. This photo sensitive forming polymer was coated onto the pre-treated silicon master and the glass backplane including the adhesion promoter was inserted. Then, the stack was cured with UV light for 20 minutes and demolded manually (for comparison see Figure 2).

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C. Micro Laser Transmission Welding

If there is a need for similar substrates with no absorbance material inside the use of an absorber coating onto at least one of two transparent polymers could fulfill these requirements. Therefore a planar cover sheet was spin coated with the absorbing liquid (Clearweld LD240F) using an Suss RC8 spin coater with 1000 rpm and a volume of about 2 ml absorber liquid. The most challenging aspect for laser welding in micro ranges is reaching a good contact between the substrates. Here a special demonstrator tool with an integrated fiber laser system (IPG Laser GmbH) was developed, pressing the two substrates together and performing the laser treatment (3D-Micromac AG, Figure 6). Regarding the adapter the substrates could be pressed together with a pressure up to 6 bar. A glass window enables the laser beam transmission.
The laser was used in continuous wave as well as in pulsed wave modus with a wavelength of 1070 nm and a power of 100 W. The infrared laser was absorbed by the Clearweld layer in-between the substrates and the resulting heat has molten the surrounding polymer material.

This led to successful joints which were characterized with a pull test as well as SEM, Figure 7) and polarization microscopy, Figure 8) showing the bonding quality. Special test structures like a striped micro chevron pattern were used for embossing and welding [3]. The measurements of the maximum force for breaking up the bond interface were performed with a pull tester. In case of thick substrates (ca. 1 mm) the test could be evaluated well and the results showed a maximum force between 2 N and 4 N (Figure 9 right). Regarding of certain difficulties like non-conformal welding area and test area the results has to be improved with further investigations.

III – Conclusion and Outlook

Within this paper a polymer replication and joining technology was described to realize micro fluidic structures and minimized welding zones for laser transmission welding. Furthermore the master development and the fabrication of working stamps as well as the realization of the structure transfer by using hot embossing was introduced. The process results in structured PMMA material and shows a high dimensional accuracy regarding duplication precision. In dependence of the feature size the processes hot embossing and thermal imprinting are almost similar used. Although the smallest bonding interface areas are not satisfied joined, the principle of minimizing the influence of laser energy could be shown by the implementation of special laser welding support structures. Further work has to be done regarding the laser welding equipment and the welding area has to be increased significantly to fulfill also requirements on effective fabrication processes.

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References

