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Characterisation of PMMA microfluidic channels and devices fabricated by hot embossing and sealed by direct bonding

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ABSTRACT

In this study we fabricated a silicon-based stamp with various microchannel arrays, and demonstrated successful replication of the stamp microstructure on poly methyl methacrylate (PMMA) substrates. We used maskless UV lithography for the production of the micro-structured stamp. Thermal imprint lithography was used to fabricate microfeatured fluidic platforms on PMMA substrates, as well as to bond PMMA lids on the fluidic platforms. The microfeature in the silicon-based (silicon wafer coated with SU-8) stamp includes microchannel arrays of approximately 30 μm in depth and 5 mm in width. We produced various channels without pillars, as well as with SU-8 pillars in the range of 50–100 μm wide and 6 μm in height. PMMA discs of 1 mm thickness were utilized as the molding substrate. We found 10 kN applied force and 100 °C embossing temperature were optimum for transferring the microstructure to the PMMA substrate.

1. Introduction

The basic requirements for microfluidic devices commercialization are economical fabrication, large scale production and good sensitivity. Microfluidic devices based on silicon, glass, quartz and plastic has been widely studied in the past ten years. The silicon and glass-based material often induces problems, such as lack of optical clarity, low impact strength and poor-compatibility, thus limiting its widespread usage in microfluidic devices. On the other hand, the importance of micro-structures on polymers is increasing, particularly when considered as a low-cost alternative to the silicon- or glass-based MEMS technologies, for single-use disposable biomedical sensors. Additionally, polymer-based materials offer a wide range of physical and chemical properties, such as low electrical conductivity and high chemical stability. In recent years, many polymer-based microfabrication techniques [1] via microinjection molding [2,3], casting [4,5], and micro-hot embossing [6,7] have been developed.

In polymer-based microfabrication techniques, microinjection molding is most popular and generally used for micromolding in the industry. However, compared to the microinjection molding, hot embossing provides several advantages such as a relatively low-cost for embossing tools, simple operation and higher accuracy in the replication of small features. The hot embossing process introduces less residual stress in the polymer because the polymer stretches for a very short distance from the substrate into microstructure during hot embossing. As a result, the molded parts are well suited for optical components. In addition, the temperature variation range for the polymer is smaller than that required in injection molding, thus can reduce shrinkage during cooling and the friction forces acting on the microfeatures during de-molding. Hot embossing includes several steps and details have been reported elsewhere [1]. The embossing master stamp can be a silicon wafer, glass, electroplated nickel mold or other stamp with microfeatures. Still, micro-hot embossing is facing challenge in terms of process feasibility, since it is difficult to make the polymer to fill completely into microfeatured geometry of high aspect ratio and it is also delicate to separate the embossed structures from the mold without breakage.

In this paper, the correlation between the dimensions of the master stamps features and the corresponding replicated features

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was analysed along with the fluid flow behaviour in the channel. The bonding between microfluidic structures and lids was leak-tested was carried on these devices by flowing colored dye.

2. Experimental

2.1. Microchannel stamp fabrication

The maskless UV lithographic technique was employed for the production of the micro-structured stamp. In this study, the SU-8 (SU-8 is a photopatternable epoxy resin) micro-structures were fabricated on a 4 inches silicon wafer. The SU-8 is a viscous and adhesive substance commonly used in lithographic process to create well-defined and stiff pattern. Prior to fabrication the silicon substrate is cleaned first with piranha solution ($H_2SO_4 + H_2O_2$) and then with acetone and de-ionized water before dehydration for 30 min on a hot plate at 65 °C. The baking ensures good adhesion of the SU-8 to the Si substrate. A 50 μm thick layer of SU-8 photoresist is spun onto the Si substrate at a spin speed of 3000 rpm and pre-baked on a hotplate (65 °C for 5 min and 95 °C for 15 min). The SU-8 is patterned by maskless photolithography system, crosslinked by baking on a hotplate (65 °C for 1 min and 95 °C for 4 min) and developed in standard SU-8 developer for 4–6 min. The negative resist SU-8 is used to create a pattern on a wafer that would be embossed directly to the plastic. Etching was not required as the pattern was very thick and strong.

2.2. Hot embossing and bonding of PMMA devices

Transparent PMMA discs of 4 inch diameter and 1 mm thickness was utilized as molding substrate of which the glass transition temperature was about 115 °C. A hot embossing system (EVG-520HE) with maximum loading force of 40 kN and maximum temperature range of 550 °C is used for the experiments. The system allows evacuation of its process chamber down to less than 10^{-5} mbar and supports fully automated and computer-controlled process flow. In addition, the top and bottom chucks have independent temperature control. The hot embossing bonding parameters were 5–15 kN applied force, temperature from 90 to 115 °C, and 5 min embossing time. After embossing, the polymer substrate was retained in the chamber and cooled down to less than 80 °C, then it was separated from the mold. The total cycle time was between 20 and 30 min. After de-molding, the replication accuracies of embossed microfeature for microchannel dimensions were examined and compared with the dimensions of the stamp.

3. Results and discussion

Maskless UV lithography was used to produce micro-structured stamp based on SU-8 photoresist coated on silicon substrate. The microfeature in the silicon stamp includes microchannel arrays of approximately 30 μm in depth and 5 mm in length. The stamp contains various channels without pillars, as well as with SU-8 pillars in the range of 50–100 μm wide and 10 μm in height. PMMA discs of 4 inches diameter and 1 mm thickness were utilized as the molding substrate. One PMMA disc can accommodate at least 20 microfluidic device structures with the above mentioned dimension. These devices were further analysed by optical microscope. Fig. 1 shows a microfluidic device structure on the silicon stamp.

The EVG520HE, a hot embossing system was used for two reasons firstly, to replicate microfeatured fluidic platforms from silicon stamp onto a PMMA substrate. Secondly, to bond PMMA lids on the replicated fluidic platforms [8]. After several optimization tests for the process parameters with pressure in the range of 5–15 kN and temperature from 90 °C to 115 °C, 10 kN applied force and 100 °C embossing temperature was found to be optimum for transferring the micro-structure to the PMMA substrate without any defects [9]. An example of a thermally imprinted microfluidic channel with square pillars of 100 μm width is shown in Fig. 2. It was observed that there was no defect on the PMMA pillars and they all are at uniform height which was further verified by surface profilometer. The PMMA lid with appropriate inlet and outlet holes was bonded onto the fabricated channels using a hot embossing system and the bonding was leak-tested by flowing colored dye through it. It was observed that there was no defect on the PMMA to PMMA bonding. Bonding strength is a key factor when evaluating the performance of any microfluidic device. Fig. 3 illustrates that there was no leakage in fluid flow when a colored dye was allowed to flow in that microchannel. This study indicates the substrate and the lid were sealed properly as there was no leakage along the sidewall.

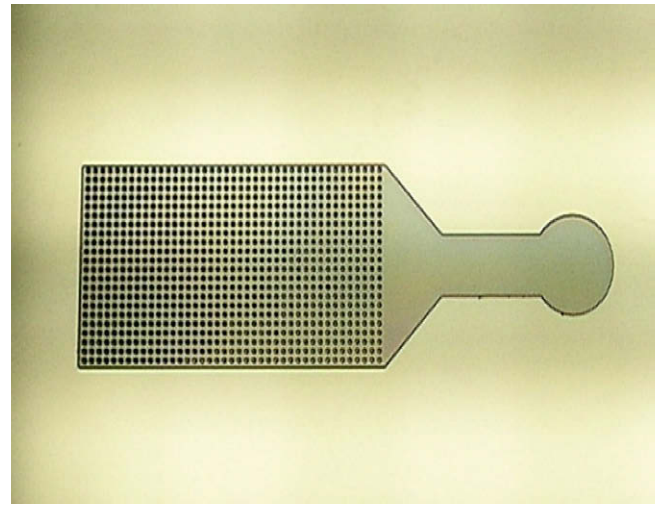

Fig. 1. An optical image of Si stamp with microfluidic channel and SU-8 pillars.

The capillary driven flow phenomenon in the microchannel is considered in this study. The capillary driven flows are purely governed by the forces associated with surface tension [10] and offer positive flow enhancement effect. Microfluidic imaging is used to experimentally visualize the interface movement in the micro-

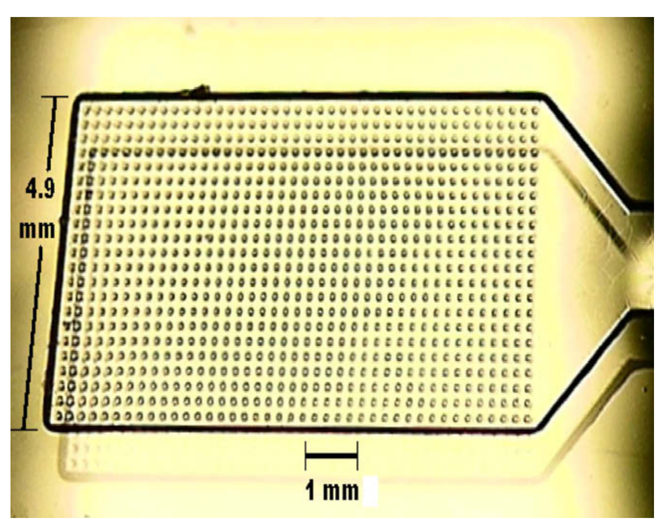

Fig. 2. An optical image of a microfluidic channel thermally imprinted on PMMA with square pillars of 100 μm width.