International Communications in Heat and Mass Transfer 42 (2013) 55–61

Contents lists available at SciVerse ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Study on the replication accuracy of polymer hot embossed microchannels ☆

Ming-Chung Lin [a], Jung-Peng Yeh [a], Shia-Chung Chen [b,c], Rean-Der Chien [a,*], Cheng-Li Hsu [b]

[a] Department of Mechanical Engineering, Taoyuan Innovation Institute of Technology, Chung-Li 32091, Taiwan, ROC
[b] Department of Mechanical Engineering, Chung Yuan Christian University, Chung-Li 32023, Taiwan, ROC
[c] R & D Center for Mold and Molding Technology, Chung Yuan Christian University, Chung-Li 32023, Taiwan, ROC

ARTICLE INFO

Available online 31 December 2012

Keywords:
Hot embossing
LIGA like
Microchannel
Replication accuracy
Microinjection molding

ABSTRACT

Microfabrication of polymers is becoming increasingly important and considered as low-cost alternative to the silicon or glass-based microelectromechanical systems technologies. However, most of hot embossing studies were done on thin films that may not fulfill the structural requirements of the products. In this study, micromolding via hot embossing was applied to microfeatured fluidic platform used for DNA/RNA test. The microfeature in the stamp of 127 mm diameter and 0.22 mm thickness includes microchannel array of approximately 30 μm in depth and 50 μm in width. A PMMA film of 1 mm thickness was utilized as molding substrate. In this work, the effects of molding conditions on the replication accuracy of microfeatures were investigated. In addition, the replication accuracies of microfeatures at various stamp positions due to the effects of density of microchannel, constraint condition, and normal pressure distribution were also discussed. The imprint width and depth of microchannels were analyzed and correlated. It was found that applied load, embossing temperature, and embossing time all significantly affect the molding accuracy. The accuracies of the imprint depth and width increase with the embossing load, temperature, and time until the associated dimensions reach saturated values. Basically, 18 kN applied force and 135 °C embossing temperature provided acceptable results considering reasonable cycle time. Regarding the effects of positions on the imprint replication accuracy, we found that closer to the center of molded parts produces better replication accuracy.

1. Introduction

Nowadays the microelectromechanical systems (MEMS) applications in the life science (such as DNA sequencing or clinical diagnostics devices) are in great demand. The commercialization of MEMS technology requires low-cost fabrication and high-volume production. Silicon-based MEMS products have good surface quality but are usually expensive and are not suitable for low-cost mass production. In addition, Si-based materials often induce problems, such as lack of optical clarity, low impact strength, and poor compatibility, thus limiting their widespread usage in MEMS products. Hence, it is worthy of establishing MEMS products based on non-silicon based materials. 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 for applications of bio- and chemical-MEMS. Polymer-based materials offer a wide range of physical and chemical properties (such as low electrical conductivity and high chemical stability), and also have the advantages of low cost and easy processing for mass production.

Among the micromolding processes, hot embossing of polymer films to create microfeatured pattern is one of the most important and promising technologies that has recently been developed. The relatively expensive step of microfabrication is only the single master or stamp production and from that identical structures can be reproduced in mass quantity. The embossing master can be a wafer, glass, electroplated nickel mold, or other stamps with microfeatures. Because it is a suitable and flexible process for the fabrication of polymer microfeatured components, it gradually shows commercial potential, particularly in the field of microfluidic/biomedical and micro-optical products. So far, there have been many successful replications of the microfeatures of stamps, including micro mirrors, microgrooves, and lens cavities for fiber communications [8]. It is expected that hot embossing will be used for MEMS in chemistry or life science (such as optical sensor and biochip) field as well. Hot embossing includes several steps. First, a polymer substrate is inserted into the molding machine, afterward; it is heated to above a certain temperature (glass transition temperature, T_g). Then, a mold (stamp or master) with micro features fabricated by CNC-machining or LIGA-type method is pressed against the substrate in an evacuated chamber, allowing the pattern to be fully transferred onto the substrate (embossing). Finally, after a certain contact time between the mold and substrate, the setup is cooled down below T_g, followed by separating the substrate from the mold (de-embossing). Fig. 1 shows the schematic of a typical stacking sequence, including stamp, substrate, and chucks used in hot embossing process. In polymer-based microfabrication techniques, microinjection molding is most popularly used for micromolding in industry. However, compared with microinjection molding, hot embossing provides several advantages, such as relatively low cost for embossing

☆ Communicated by W.J. Minkowycz.
* Corresponding author.
E-mail address: chienreander@yahoo.com.tw (R.-D. Chien).

0735-1933/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.icheatmasstransfer.2012.12.008

tools, simple operation, simple process steps (e.g., less processing parameters and large process window), and high replication accuracy for small features. It also introduces less residual stress in the polymer because the polymer only stretches or flows only a very short distance from the substrate into the microstructure during hot embossing. As a result, the molded parts are well suited for optical components, such as lens and wave-guides. In addition, the temperature variation range for the polymer is smaller than that required in injection molding, thus it can reduce the shrinkage during cooling and the friction forces acting on the microfeatures during demolding. Components with delicate microfeatures are more suitably produced by hot embossing than by microinjection molding. Still, micro hot embossing is facing a challenge in terms of process feasibility, because it is difficult to make the polymer to fill completely into microfeatured geometry with a high aspect ratio, and it is also difficult to separate the embossed structures from the mold without breakage. The correlation of the replication accuracy to all contributing parameters is quite a complicated issue.

A number of studies have been conducted in recent years to investigate the hot embossing process for micro- and nano-structures. The wet-etched silicon molds used for polymer embossing exhibit special advantage because of their excellent surface quality and easy mold release [9]. Usage of polymer substrates with various molecular weights for the hot embossing process was reported [10]. Influence of hot embossing on the flow patterns under both isothermal and non-isothermal conditions was investigated by Juang et al. [11]. The results showed that the deformation patterns of the polymer film in these two conditions are substantially different. This indicates the thermal history of the embossing process may play an important role for molding quality. Chang and Yang [12] reported an innovative method for hot embossing by applying gas pressure directly to press the mold and the substrate. This can improve replication accuracy because more uniform embossing pressure was applied across the entire substrate. Becker and Heim also provided some suggestions in processing conditions when hot embossing polymer parts with micro-sized feature [13]. The suggestions include: (1) the thermal variation should be limited between 25 and 40 °C to minimize thermally-induced stresses, (2) the embossing pressure must be around 0.5–2 kN/cm^2. Ressier et al. indicated that the quality of micrometric pattern replica by hot embossing lithography (HEL) strongly depends on the size of the mold features [14]. Although hot embossing has been used in microfabrication for several years, effects of embossing conditions on the replication accuracy of microfluidic channel have not yet been fully and systematically investigated. Particularly, most of the studies were conducted on thin films that may not fulfill the structural requirements of the products. In the present study, UV light aligner was used to prepare silicon based SU-8 photoresist, followed by electroforming to make Ni–Co-based biochip stamp. The microfeature in the stamp has a microchannel array of approximately 30 μm in depth and 50 μm in width. 1 mm thick poly(methyl methacrylate) (PMMA) substrate was hot embossed to generate microfeatured channel array designed for biochip devices. Then, the embossed dimensions of the microchannel in the device were measured using a 3-D laser microscope. A set of systematic experiments is conducted to correlate the effect of embossing conditions, including applied embossing load, embossing temperature, and embossing time, on the replication accuracies of microfeatures, including the imprint depth and imprint width of the microchannels. In addition, the replication accuracies of microfeatures at different stamp positions because of the effect of the microchannel density, constraint condition, and normal pressure distribution, were also discussed. This study may lead to a better understanding of the effects of the embossing characteristics on the fabrication of microfluidic channels within a polymer substrate.

2. Experimental

In this study, LIGA like processes using UV light aligner were first implemented to prepare silicon based SU-8 photoresist, followed by electroforming to make Ni–Co based biochip mold insert, as shown in Fig. 2. The stamp used in hot embossing was 127 mm in diameter and 0.22 mm in thickness and patterned with microfeatured channel array structure. Basically, the microchannels in the stamp have dimensions of approximately 30 μm depth and 50 μm width. The draft angle at the sidewall of the microchannel is approximately 8.1° to 8.4° so that in the mold release step it can eliminate structural deformation because of frictional or shear forces between the embossing master and the substrate. Transparent PMMA of 1 mm thickness (supplied by Mitsubishi Corp., Japan) was utilized as molding substrate with glass transition temperature of approximately 100 °C. Because this device was designed for the biomedical application, the mold release agent was not allowed to use to avoid contamination. For evaluating the replication accuracy of the embossed part, the associated dimensions on four chosen positions (designated by (T), (A), (C) and (D)) of the stamp were measured using a 3-D laser microscope (maximum magnification 16,000, Keyence Corp., Japan), as shown in Fig. 2(a). Fig. 2(a) also shows the 3-D laser

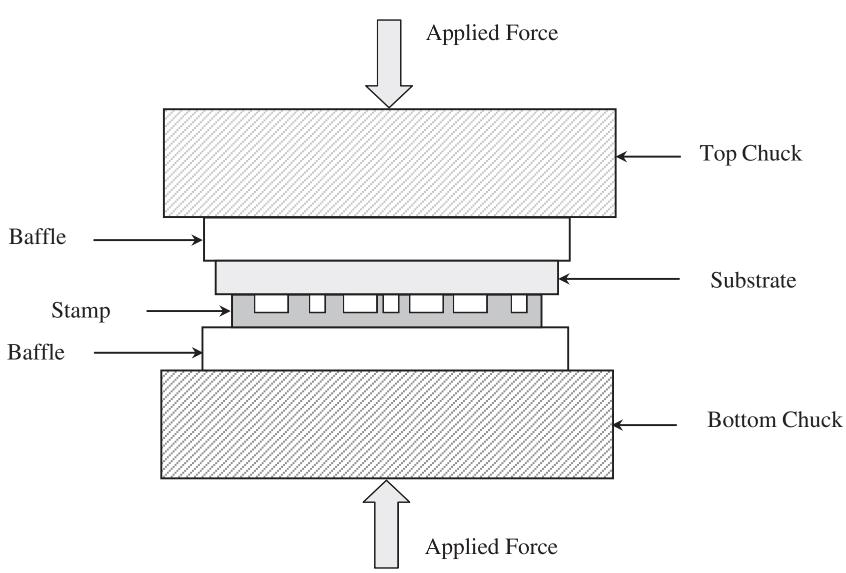

Fig. 1. Stacking sequence used in hot embossing. Stamp, substrate, and chucks are shown and piston force is applied on the topside chuck.