SOFT EMBOSsing OF MICROFLUIDIC DEVICES

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Abstract

Elastomeric tools created from machined or microfabricated masters were used to emboss plastic parts that closely resemble mass-produced, injection molded parts. The advantages of this approach include: rapid creation of embossing tools, ease of part removal from the tool, the ability to simultaneously emboss large (mm), small (µm), and high aspect ratio features, great flexibility in material choice and relatively rapid (minutes) cycle times.

Keywords: Embossing, Elastomer, Centrifugal Microfluidics, LabCD

1. Introduction

The last decade has seen a trend toward the use of polymeric materials for the fabrication of microfluidic devices [1,2]. Reduced cost, chemical compatibility and optical properties are often cited as reasons for choosing a polymer over an inorganic material like silicon or glass. While some groups are advancing the use of curable elastomers as device materials [3,4], embossing and injection molding of thermoplastic resins continue to be the preferred methods for mass production. With embossing or injection molding, the resin is brought in contact with a microstructured substrate, or tool. Under application of time-dependent pressure and temperature, the polymer fills all voids in the tool cavity and forms a conforming part that is the “negative” of the tool. As these fabrication approaches are conventionally practiced, the tool is inflexible and made from a hard metal like steel or nickel. Rigidity coupled with the high surface area typical of these devices makes part removal a challenge that is often overcome by the use of mold releases, which potentially compromise device performance.

Because elastomeric tools are deformable and resilient, they allow the straightforward and repeated forming and separation of devices from a tool without significant damage to the devices or signs of wear on the tool. The use of an elastomeric tool eliminates the need for mold releases and significant mechanical forces, and the associated mechanical pins and plates that are often required for part ejection when a metal tool is used. Furthermore, elastomeric embossing tools can be quickly and easily created from a variety of masters, allowing for the rapid prototyping of microfluidic devices that closely resemble injection molded parts.

2. Experimental

Masters were created by machining features in cast PMMA (Atofina, Philadelphia, PA) using a CNC milling machine (Intelitek, Inc., Manchester, NH) with a minimum tool
size of 127\(\mu m\). In some cases (not demonstrated here), masters were created by standard SU-8 photolithographic techniques. Elastomeric tools were created by mixing, pouring and degassing high durometer silicone (Shin-Etsu Chemical Co., Akron, OH) in the machined acrylic masters. The tools were cured at room temperature overnight and were placed on the top and bottom plate of a custom made embossing press that is capable of operating in force or displacement control modes. Plastic resin pellets or preformed resin “charges” were placed between the two tools and the tools were heated above the glass transition temperature of the plastic. The assembly was exposed to a profile of heat and temperature, allowing the polymer to take a shape conformal to the molds (Figure 1A). After cooling, the molds were easily peeled away from the rigid plastic part (Figure 1B). Through holes in the part could be achieved by extending a large feature in the tool through the entire thickness of the cavity, or extending smaller, mating features from both top and bottom tools.

Figure 1. Schematic of the soft embossing approach.

Although a variety of different polymer resins (acrylic, polystyrene, polypropylene, cyclic olefin copolymer) have been successfully used with this approach, the examples presented here were produced using an injection moldable grade of acrylic (PMMA VOD-100; Atofina, Philadelphia, PA). A 24g preformed circular charge of VOD-100 was placed between two circular elastomeric tools with diameters of 130mm. One tool contained all the features necessary for creating a centrifugal microfluidic system [5] with 96 individual subunits, including both ‘macro’ features (1.4mm high x 0.4mm wide) and ‘micro’ features (50\(\mu m\) x 127\(\mu m\)). The other tool contained features allowing through holes for air access. The tools were brought from room temperature to 190°C within 2 minutes while the clamping force was slowly increased to 3kN. After a 6 minute dwell time, the tools were cooled to room temperature within 2 minutes, the force was reduced and the tools were peeled off the embossed part. The tools could be used repeatedly with little degradation. Although a number of different bonding approaches could be employed (adhesives, ultrasonic welding, etc), the parts shown here were bonded to preformed PMMA lids via thermal diffusion bonding.
3. Results and Discussion

A portion of the elastomeric mold used to emboss a centrifugal microfluidic system with 96 individual subunits on a compact disc sized footprint is shown in Figure 2A. Note that both macro and micro features are contained in the same mold, eliminating the need for multipart assembly and the resulting alignment challenges. The VOD-100 polymer part produced by embossing with this mold is shown in Figure 2B. Although this particular part was produced with a single tool resulting in incomplete through holes, two tools have been successfully used to emboss fully functional parts. Note that the fidelity between the part and the tool is very good. The quality of embossed features was consistent over the entire 130mm diameter and was extremely reproducible.

A cross section of an embossed part thermally bonded to a preformed lid is shown in Figure 3. Both ‘macro’ and ‘micro’ features were created with approximately equal fidelity. In most cases, bonded parts contained features that were approximately 10-20μm shallower than designed, presumably due to compression of the elastomeric tool or deformation at bonding. As seen in Figure 3, there were occasional, small lateral deformations of some features. This may be due to some combination of embossing, bonding or preparation of the sample for photography.

Figure 2. High durometer silicone microstructured tool containing both macro and micro features (A) and the corresponding structures embossed in PMMA VOD-100 (B).
Centrifugal microfluidic devices embossed with this technique were fully functional and included such features as sample introduction, volume metering, common reagent distribution, capillary valving, mixing and incubation/detection. This soft embossing technique has also been used to create diffraction gratings with spacings as small as 15μm. The simplicity and fidelity of this technique should allow its use for a variety of prototyping applications.

References


