A RAPID PROTOTYPING MICROFABRICATION METHOD USING HIGH-TEMPERATURE CASTABLE MATERIAL FOR HIGH-THROUGHPUT MICRO-INJECTION MOLDING

Jungyoup (Jay) Han[1]*, Aniruddha Puntambekar[1], Se Hwan Lee[1], and Chong H. Ahn[1,2]
[1]Siloam Biosciences, Inc., Cincinnati, OH 45240, USA and
[2]School of Electronics & Computing Systems, University of Cincinnati, Cincinnati, OH 45221, USA

ABSTRACT

In this research, a new scheme of rapid prototyping using high-temperature castable materials for microfabrication of polymer lab-on-a-chip, which is used for micro-injection molding is proposed and characterized with extension of the replaceable mold disk technology. Showing perfect master mold creation of ultra-high density channel with aspect ratio of ~0.7, the proposed process is well fitted for rapidly turn-around prototyping microfabrication to accommodate a master mold.

KEYWORDS: Rapid Prototyping, Microfabrication, High-Temperature Castable Material, Micro-Injection Molding

INTRODUCTION

The most commonly used approach for microfabrication of polymer lab-on-a-chip devices is schematically illustrated in Figure 1 describing processing steps as 1) Mold disk preparation, 2) UV-LIGA process for mold fabrication, 3) Plastic replication by injection or embossing molding techniques, 4) Post-processing for interconnects, 5) Assembly and/or bonding, 6) Microfluidic interconnects assembly (optional). A significant step in rapid prototyping of polymer lab-on-a-chip devices is the ability to eliminate some steps in the UV-LIGA process. The standard UV-LIGA process consists of thick photoresist (SU-8™) photolithography followed by electroplating pattern structure on a metal master mold such as Nickel substrate. The electroplating process is inherently slow and leads to non-uniformity of channel dimensions due to current crowding effects. A suitable solution for prototyping purposes is the use of high-temperature (HT) aluminum-filled epoxies [1]. Since the HT castable epoxies have considerably lower mechanical strength than metallic parts, it can typically produce between 50 to 1,000 parts depending on the part geometry. This range is ideally suited for microfluidic evaluation studies and allows researchers to test concepts rapidly without investing significant cost and/or effort in UV-LIGA molds.

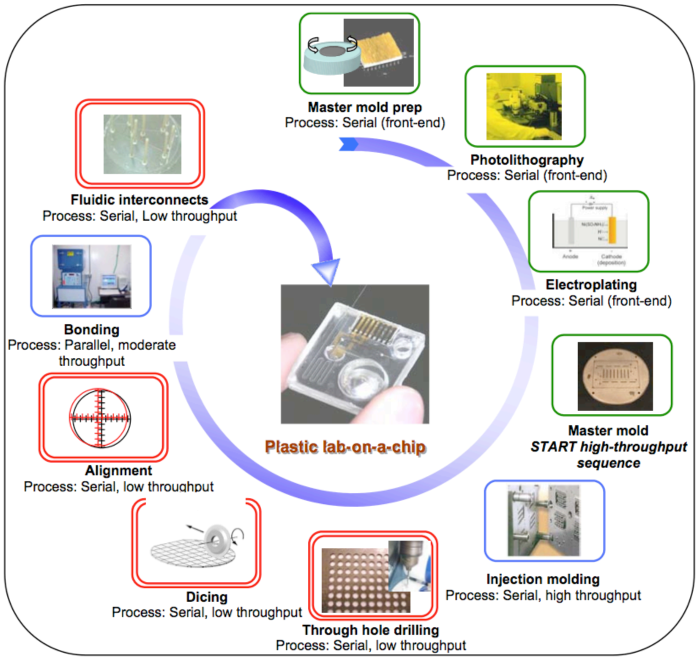

Figure 1: Conventional process sequence for fabrication of plastic lab-on-a-chips, where processes with double borders signify bottlenecks to high throughput. Front-end processes are also serial in nature but do not affect the high throughput manufacturing sequence. High temperature epoxies have been used for rapid prototyping on a macro-scale previously [2]. A range of rapid prototyping techniques are described on the "Worldwide rapid prototyping directory" including the use of high temperature epoxies. In this research, a high temperature epoxy is used to manufacture a prototype insert for injection molding, instead of a metallic mold insert.

MATERIALS AND FABRICATION

After evaluating different high-temperature epoxies, RENCAST™ 2000 [3] and DURALCO™ 4540 [4] with very high viscosities (~30,000cP after mixing) were shortlisted in Table 1 for this research. With both materials, the curing reaction is an exothermic process and high viscosities that causes air-bubbles which are trapped and form voids within the material.

Table 1. High temperature epoxy comparison [3, 4]

Name	RENCAST™-2000	DURALCO™ 4540
Vendor	Freeman Manufacturing, OH, USA	Cotronics Corp., NY, USA
Heat deflection temp (°C)	230	260
Compressive strength (psi)	25,500	Not specified by manufacturer
Flexural strength (psi)	14,000	Not specified by manufacturer
Tensile strength (psi)	9,000	10,000
Viscosity (cP)	Resin: paste Hardener: 20-30 Mixed: 30,000	Resin: paste Hardener: 20-30 Mixed: 30,000
Gel Time (min)	60 min	20 min
Cure shrink	0.001 in/in	0.1%
Hardness (Shore D)	91	80
Thermal conductivity (W/mK)	1.65	5.05
Cure	Initial – 3 hr @ 60°C Post – 6hr @ 150°C	Initial - 24 hr @ RT Post – 4 hr @ 125°C

Hence, as seen in Figure 2, we have developed a two-step process for mold fabrication. Initially, a very small quantity (< 5 gms) of the epoxy material is "squeegeed" onto the silicone replica mold. This ensures that the material properly fills the microstructure patterns and also forms a very thin layer. Any air-bubbles created during cure can easily escape the thin layer. After partial cure, a second layer of the epoxy is added to the desired thickness.

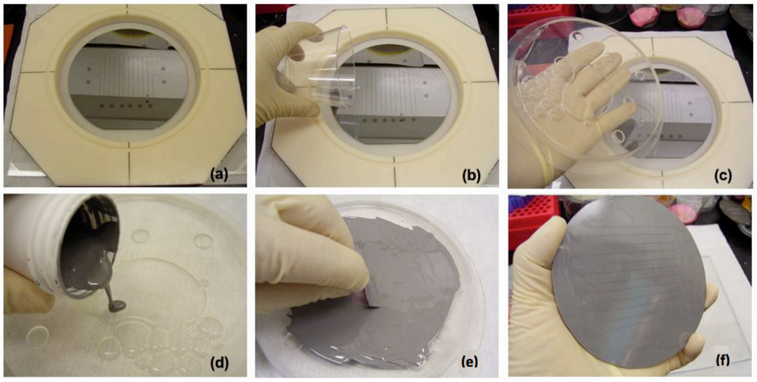

Figure 2: Photographs of mold fabrication steps for RENCAST™ 2000 and DURALCO™ 4540 high-temperature epoxy molds; (a), (b), (c) Silicone casting onto the microstructure on Si substrate with a specific enclosure; (d), (e) after pouring small quantity of the high-temperature epoxy, the material is "squeegeed" onto the silicone replica mold using a rigid plastic blade for escaping air-bubbles; (i) the second layer is added to the final target thickness after partial cure.

An additional parameter of interest in this process is the total "pot life" of the epoxy. Both epoxies are 2-component mixtures that start reacting immediately after mixing. The DURALCO™ 4540 maintains a gel like viscosity for ~ 20 min after which it becomes too viscous even for the squeegee process while the RENCAST™ 2000 maintains the gel-like state for ~ 60 minutes which makes it easier for a conformal copy of the microstructures.

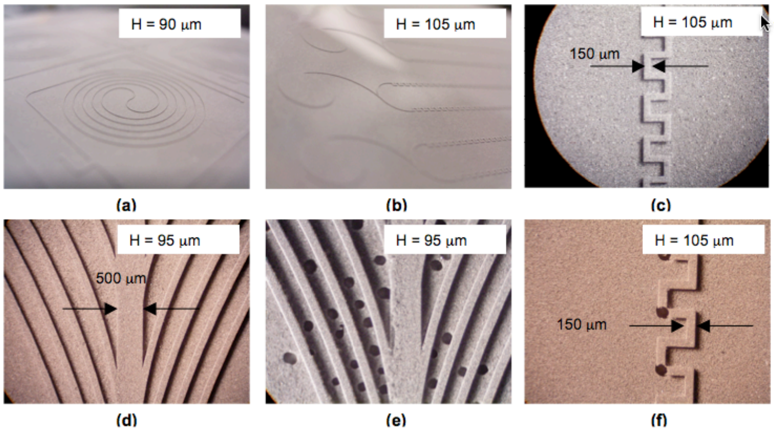

Figure 3: Microphotographs of RENCAST™ 2000 and DURALCO™ 4540 aluminum-filled high-temperature epoxy molds: (a), (b), (c), (d) images of RENCAST™ 2000 molds; (e), (f) images of DURALCO™ 4540 molds; (e) and (f) show voids in mold due to rapid curing of DURALCO™ 4540 material.

Figure 3 shows images of mold fabricated using both materials. As shown in Figure 3, due to shorter working time, the DURALCO™ 4540 leads to bubbles within densely packed microstructures, whereas the RENCAST™ 2000 is easier to copy to create almost perfect replicas of the original patterns. Note that Figure 3 (c) shows perfect reproduction of ultra-high density channel with AR (aspect ratio) of ~ 0.7.

EXPERIMENTAL RESULTS

For characterizing the two epoxies, the first step was evaluating the surface roughness of the master molds. Cotronics Corp. was able to confirm that the average grain size of the Al filing in the DURALCO™ 4540 material is ~ 100 nm. Similar data for the RENCAST™ 2000 is not available. Figure 4 shows scan profilometer data for the two materials clearly showing that the RENCAST™ 2000 has significantly lower surface roughness.

We have also completed preliminary evaluation of mechanical robustness of the two materials. A microfluidic channel pattern consisting of channels ~ 250 µm wide and ~ 80 µm deep were fabricated for both materials. The molds were used for embossing tests and both materials could reproduce > 20 molds without damage in case of the channel width 150 µm and depth 80 µm. In all cases, the length of the microstructure (microfluidic channel pattern) was at least 10x (or more) of the width. At aspect ratio of ~0.5 or lower, the RENCAST™ 2000 seems to exhibit slightly higher mechanical strength than the DURALCO™ 4540. Figure 5(a) shows the percentage (area) of patterns lost with increasing number of injection mold cycles. The data was analyzed using ImageJ™, image analysis software [5]. The mold experience two significant force points in the molding cycle: (a) when the molten plastic is injected at >10,000 psi injection pressure and (b) during ejection when the part is pushed abruptly from the mold. Figure 5(b) shows compressive strength of RENCAST™ 2000 was evaluated with cylinder samples having diameter of 1/8", 1/4", 3/8", 1/2", and 1".

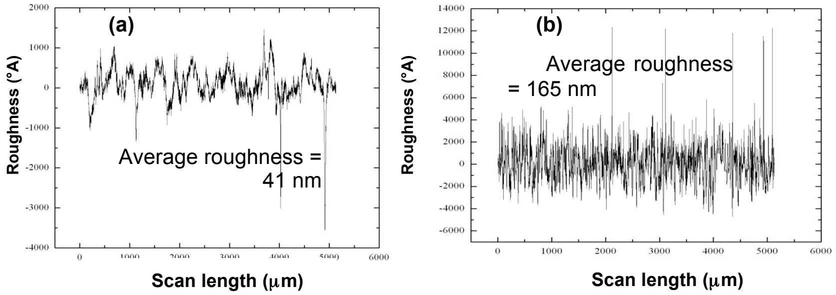

Figure 4: Scan profilometer surface roughness measurement for (a) RENCAST™ 2000 and (b) DURALCO™ 4540. Please note the difference in scale for the two images (Y-axis for (a) extends to 1400 nm and (b) extends to 200 nm).

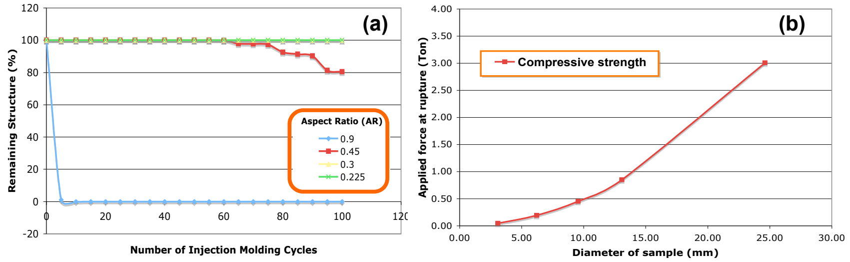

Figure 5: (a) % Remaining structure of RENCAST™ 2000 mold as an evaluation (for depth = 90 µm, pattern width 100 µm, 200 µm, 300 µm, and 400 µm,).and (b) Compressive strength for RENCAST™ 2000 mold

CONCLUSION

The proposed scheme clearly shows rapid, low-cost and easier prototyping microfabrication steps to allow researchers to test proof-of-concepts thru successful characterization rapidly without investing significant cost and/or effort in UV-LIGA molds. This process is well suitable for rapid prototyping, and responds to a pressing demand in micro-injection molding as a microfabrication process of polymer lab-on-a-chip or µTAS.

ACKNOWLEDGEMENTS

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[5] http://rsb.info.nih.gov/ij/

CONTACT

*J. Han, tel: +1-513-429-2976; jhan@siloambio.com