International Journal of Computational Engineering Science
Vol. 0, No. 0 (2002) 000–000


# SU-8 ON PMMA -- A NEW TECHNOLOGY FOR MICROFLUIDICS

T.Q. TRUONG and N.T. NGUYEN
*School of Mechanical and Production Engineering, Nanyang Technological University*
*50 Nanyang Avenue, 639798 Singapore*

Received (received date)
Revised (revised date)

Conventional SU-8 lithography process for fabricating microfluidic devices often uses silicon or glass as substrate materials. Since silicon and glass are very hard and brittle, drilling fluid access holes or dicing the substrates into individual devices are difficult. We investigated the use of polymethylmethacrylate (PMMA) as a new substrate material. PMMA, an amorphous thermoplastic, was chosen because it is easy to drill or cut, biocompatible, transparent, and hundreds of times cheaper than silicon or glass wafers. Moreover, its thermal expansion coefficient ideally matches that of SU-8. PMMA poorly resists solvents, and has low glass transition temperature (105$^o$C). Thus, the conventional process was modified. The substrate was only cleaned with isopropyl alcohol and deionized water. The baking temperature was lowered to 90$^o$C. In addition, a "base layer" of SU-8, helping to achieve a high quality structural pattern, was coated before coating the actual structural SU-8 layer. A Tesla valve, a non-moving part microfluidic valve, was successfully fabricated in SU-8 using the presented process. However, the PMMA substrate bowed due to the thermal residual during baking steps. Despite the bowing problem, which can be solved by increasing substrate thickness, we conclude that PMMA is a promising material for SU-8 process.

*Keywords:* Microfluidics; SU-8; PMMA; Fabrication; Photolithography.

## 1. Introduction

Microfluidics, a discipline dealing with the miniaturization of fluidic devices, becomes increasingly important with the growth of life science. Microfluidic devices, capable of detecting and handling microscopic fluid amounts, are the key technologies for genomics, proteomics and drug discovery [1].

The majority of microfluidic devices have been realized on silicon [2–4] and glass, because the fabrication technologies for them are matured. However, the limitations of silicon and glass are materials high cost and expensive facility and equipments such as clean room, DRIE machine. With the trend of modular, low cost, and disposable microfluidic devices, cheaper materials and microfabrication technologies are needed. Several of such disposable devices were fabricated in polymers such as polymethylmethacrylate (PMMA), polyvinyl chloride, polycarbonate, polydimethylsiloxane, and SU-8. Common polymeric fabrication technologies are injection molding, hot embossing, soft lithography, and photolithography.

SU-8, a negative thick photoresist, has been widely used to fabricate microfluidic devices such as micromixer [5], microreactors, and electrochemical detectors [6]. In a conventional SU-8 lithography process, SU-8 is spin coated on silicon or glass substrates. Although popular, silicon and glass are not ideal. First, drilling fluid access holes in silicon/glass and dicing the substrates into individual devices are difficult, and required expensive equipments such as DRIE, diamond-coated cutter or diamond-coated drill bits. Second, the thermal expansion coefficients (TEC) of silicon/glass are tens times smaller than that of SU-8. TEC mismatch is the main cause for microcracks on SU-8 film. Therefore, new substrate materials are required.

This paper reports the use of PMMA as a substrate in the SU-8 process to fabricate microchannels. PMMA, also known as Plexiglas, Perspex, Acrylic, was chosen for being easy to drill or cut, biocompatible, transparent, and cheaper than silicon or glass wafers. PMMA sheets were cut into substrates. The substrates were spin coated with SU-8, and subjected to different cleaning, baking, and developing conditions.

## 2. Experimental Section

The fabrication process is depicted in Fig. 1. The detail is discussed in the next sections.

### 2.1. *Prepare PMMA substrate*

A 3-mm-thick PMMA sheet was cut into 100-mm-diameter circular substrate. The two films protecting the PMMA were kept intact to prevent dust and oil contamination during machining, and were peeled off just before applying the SU-8. The substrate was cleaned with isopropyl alcohol (IPA), and deionized (DI) water. PMMA poorly resists to solvents, thus acetone must not be used. Finally, the substrate was dried in a convection oven at 90$^o$C for 30 minutes. PMMA has low glass transition temperature (105$^o$C) so all the baking temperatures were kept under 90$^o$C.

### 2.2. *Coating of 50-μm-thick SU-8 base layer*

Four ml of SU-2050 (Microchem Corp, USA) was dispensed onto the substrate. Spin-coating the resist at 500 rpm for 15 s, followed by 3000 rpm for 15 s produced a 50 μm thick film. This film acted as the base for the next SU-8 structural layer. The resist was soft baked in the convection oven at 65$^o$C in 2 minutes, then at 90$^o$C in 15 minutes, and allowed to cool back to room temperature (24$^o$C). Next, the resist was exposed to UV light (EV620 Mask aligner, EV Group) with an energy density of 525 mJ/cm2 through a blank mask. The resist underwent hard baking at 65$^o$C in 2 minutes and at 90$^o$C in 5 minutes. Following, a relaxation step at (65$^o$C, 2 minutes) was performed to release thermal stress in the SU-8 film.

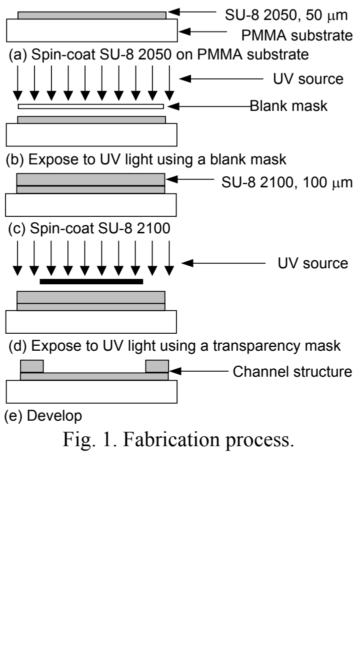


Fig. 1. Fabrication process.

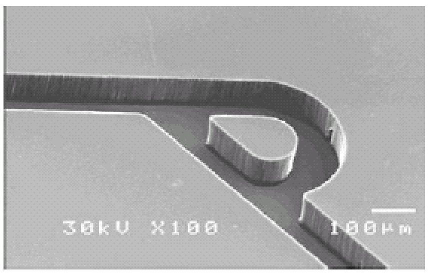


Fig. 2. SEM of the Tesla valve by SU-8 on PMMA substrate.

### 2.3. *Coating of 100-µm-thick SU-8 structural layer*

Four ml of SU-2100 was dispensed onto the first layer. The spinning speed was ramped up in 5 seconds to 500 rpm, held for 5 seconds, ramped up in 10 seconds to 2100 rpm, help for 22 seconds, and ramped down to full stop in 20 seconds. This recipe gave a 100-µm-thick film. The resist was soft baked at (10 minutes, 65$^o$C) and at (90$^o$C, 40 min). After cooling down to room temperature, it was exposed to UV light with an energy density of 525 mJ/cm2 through a transparency photomask. Following, a two-step hard bake was performed at (65$^o$C, 5 minutes) and (90$^o$C, 20 minutes). An intermediate step at (65$^o$C, 2 minutes) was introduced to release the thermal stress in the SU-8 film. The SU-8 was developed in the PGMEA developer (MicroChem Corp) for 10 minutes. It was blown dry with nitrogen.

## 3. Results and Discussions

Tesla valve, a non-moving part valve [6], was fabricated in SU-8 on PMMA using the process presented here, Fig.1. The picture shows a good quality, high resolution SU-8 structure. The followings sections are devoted to discuss the advantages as well as the limitations of the process.

### 3.1. *Circular versus rectangular substrate*

Circular substrate is preferred because it reduces the excessive edge bead associated with rectangular substrate. In our first experiment, the rectangular substrate was used, which resulted in very thick edge beads at the four sides. The edge bead was even thicker at the four corners, Fig.2. We believe, with rectangular substrate, SU-8 from two adjacent sides added up at corners. This excessive edge bead prevented the photo mask to properly contact with the majority of the resist surface during exposure, causing resolution lost.

### 3.2. *Reason for coating the 50-µm-thick based SU-8 layer*

In the some of the first experiments, the structural SU-8 was directly coated on to the PMMA substrate. After developing, the uncrosslinked SU-8 stuck to the substrate, the whitish areas in Fig. 2. The murky residual could not be cleaned off by IPA, DI water, or even acetone. An ultrasonic bath treatment did remove some of the residual, but part of the SU-8 structure was also damaged. We concluded that the residual could not be removed by normal procedures. The solution was to coat a base SU-8 layer as described in the previous section.

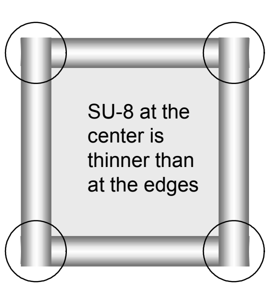


Fig. 3. Excessive edge bead at the four corners.

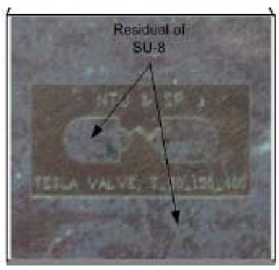


Fig. 4. The murky areas are residual of SU-8 remaining on the PMMA substrate, after developing.

### 3.3. *Cracking and Adhesion of SU-8 Film on PMMA*

PMMA and SU-8 have similar thermal expansion coefficient (TEC), Table 1. This matching results in no crack in the SU-8 film, and better film adhesion on substrate.

Table 1. TEC and Young's modulus of Si, glass, PMMA and SU-8.

| Properties | Si | Glass ($SiO_2$) | PMMA | SU-8 |
|---|---|---|---|---|
| TEC (ppm/°C) | 2.7 | 3.0 | 6.0 | 52.0 |
| Young's modulus (GPa) | 130.0 | 62.7 | 3.2 | 4.0 |

### 3.4. *Substrate Bowing*

The PMMA substrate severely bowed after post bake step. The thermal stress of the thick SU-8 film is the main cause. This also happens to silicon or glass. However, PMMA, tens times less than that of silicon or glass, is more vulnerable to bowing. Possible solution is to increase the stiffness of PMMA substrates by either increasing the thicknesses or reducing the diameter.

### 3.5. *Cost comparison*

PMMA is much cheaper than silicon or glass substrate. A simple comparison, a PMMA 1.5mm ×1.2 m×1.8 m sheet costs about $17, while a 100 mm silicon wafer costs $14. Thus PMMA is hundreds times cheaper than silicon (The costs comparison was simplified by ignoring cost of cutting and milling PMMA sheet into wafer shape).

## 4. Conclusion and Future Works

This paper has presented the SU-8 process on PMMA. It has proved that it is possible to coat SU-8 on PMMA. Good quality SU-8 film on PMMA has been achieved. It has also identified the limitation of this process, that is the PMMA bowing. The process presented here was not optimized, especially the baking time. Therefore, more experiments need to be done. Furthermore, coating of metals on PMMA should also be explored in order to fabricate more complex microfluidic devices. In conclusion, being low cost, easy to machine, transparent, and biocompatible, PMMA is a promising substrate material for SU-8 process.

## References

1. N. T. Nguyen and S. T. Wereley, *Fundamentals and Applications of Microfluidics*, Artech House, Boston (2002).
2. N.T. Nguyen, S. Schubert, S. Richer, and W. Dotzel. Hybrid-assembled micro dosing system using silicon-based micropump/valve and mass flow sensor, Sensors and Actuators A**69** (1998) 85–91.
3. D. Maillefer, et al., A high-performance silicon micropump for an implantable drug delivery system, Proc. MEMS'99, (1999) 541–546.
4. H.T.G van Lintel, F.C.M van de Pol, and S. Bouwstra. A Piezoelectric Micropump Based on Micromachining of Silicon, Sensors and Actuators A**15** (1998) 153–167.
5. Rebecca J Jackman, et al., Microfluidic systems with on-line UV detection fabricated in photodefinable epoxy, Journal of Micromechanics and Microengineering, **11** (2001) 263–269.
6. E. LHostis, et al., Microreactor and electrochemical detectors fabricated using Si and EPON SU-8, Sensors and Actuators, B**64** (2000) 156–162.
7. F.K. Forster, et al., Design, fabrication and testing of fixed-valve micro-pumps, Proc. The ASME Fluids Engineering Division, (1995) 39–44.