

Design and Fabrication of Geometrically Enhanced Micromixer for Homogenous Mixing

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Abstract. At a macro scale level, mixing is generally achieved by a turbulent flow, which makes possible of segregating the fluid in small domains, thereby leading to an increase in the contact surface and decrease in the mixing path. At low Reynolds number, the viscous effects dominate inertial effects and a completely laminar flow occurs. In the laminar flow system, fluid streams flow parallel to each other and the velocity at any location within the fluid stream is variant with pressure when boundary conditions are constant and due to the change in surface area-to-volume tension and diffusion, do not simply scale linearly from large to small devices. This makes the use of microfluidic as a mixing device difficult. Thus, the study posed to bridge this gap by created geometrically enhanced Micromixer for homogenous mixing.

Introduction

Nowadays, microfluidic technology has become mature technology. Application of microfluidic technology in various fields has increased such as macromolecule separations, enzymatic assays and cell-based assays. Various testing and analysis of fluids are enabled in micro scale through a device called lab on chip. The lab on chip is the microfluidic device which is capable of undergoing laboratory functions and biomedical analysis, in a manner competitive to bench-top instruments. Lab on chip system is developed to serve the purpose of accelerating and automation of the diagnosis process like sample holding, staining, destaining, separation, detection, sizing and quantification[1-5]. Lab-on-chip is a microfluidic device in which various laboratory functions are possible to be minimized and integrated onto a single chip which is only a few square millimeters in size. This application has been contributed in some chemical analytical process, for instance electrochemical, mass spectrometry, thermal detection, capillary electrophoresis and electrochromatography. Lab on chip involved the field of engineering, physics, chemistry, microtechnology and biotechnology[6-8]. By pumping the few drops of testing fluids, lab on chip is capable of handling this small amount of fluids and is able to automate and perform the chemical analysis alone. It is a combination of MEMS device which consists of microfluidics and mechanical flow control devices, such as micropump, microchamber, microvalve, micromixer and separators. Lab on chip is normally related to Micro Total Analysis Systems (μ TAS) which is the integration of the total sequence of lab processes in order to perform chemical analysis [9-12].

Lab on chip technology possesses several advantages, such as programmability and straight forward process integration. Lab on chip device is perfectly sealed, and hence the chance of contamination of samples is reduced. It involved very low fluid volumes consumption, in other words, less waste, lower reagents costs and less sample volumes for diagnostics. Lab on chip is also advanced in its compactness as the integration of much functionality[13-16]. The analysis is accelerated and response times is reduced because short diffusion distances, fast heating, high surface to volume ratios, small heat capacities. Lab on chip device has better process control and able to provide precise measurements since the system can response faster. The material to built lab on chip is chemically inert, so the device can be cleaned easily [17-18].

Materials and Methods

Throughout the fabrication of lab on chip device, there are several chemical material involved, such as acetone, SU-8 photoresist, PDMS, curing agent for PDMS and Isopropanol (IPA) and Glass. Acetone and IPA serve in substrate cleaning to remove the contaminants and particles. The photoresist selected to create patterns on substrate is SU8. SU-8 is a typical used epoxy-based negative photoresist which is used to create patterns with high aspect ratio structures. Su-8 is a very viscous polymer that can be spun or spread over a thickness. SU8 are available to develop vertical sidewalls of micrometer height on glass or silicon wafers. (Schumacher *et al.*, 2008) During exposure, the molecular chains of SU-8 are cross-linked and hardened. The developer used for SU-8 is 1-Methoxy-2-propanol acetate. SU-8 was used once as a high-resolution mask in fabrication process. But it is mostly used in the fabrication of micro fluidics device and MEMS parts. SU-8 has high transparency in the ultraviolet region, which allows the fabrication of thick structures with nearly vertical side walls. After exposure and developing, the high cross-linked structure has strong immunity to chemicals and radiation damage. Polydimethylsiloxane (PDMS) is the polymeric organosilicon material. It is usually used as silicon-based organic polymer for its extraordinary performance in rheology. The transparency of PDMS is high and it is chemically inert, non-flammable and non-toxic.



Fig.1, The curing and bonding process

The process steps involved are spin coating, soft baking, exposure, hard bake and development. The photoresist used is SU-8 which is a negative photoresist. Initially, very small amount of SU-8 is dropped at the centre of the silicon wafer. The speed is set to 800rpm for 10s. This process step is purposed to spread the thin SU-8 layer all over the surface of the substrate and improve the adhesion of the whole SU-8 layer on the silicon segment. After that, about 3ml of SU-8 is dropped at the centre of the wafer, and undergoes the second spin coating. The spin speed is set to 2000 rpm for 20s with the ramp up speed at 800rpm for 20s. After spin coating with SU-8, the wafer is soft baked at temperature of 65°C for 10 minutes by using hot plate. After that, the wafer is baked at the temperature of 95°C for 20 minutes. After the mold fabrication, the curing process follows. There are two methods that can be used to cure the PDMS. Upon pouring the mixture into the petri dish, the dish is left on a flat surface for 24 hours. Another alternative involve the implementation of vacuum chamber Fig.1.

The petri dish is inserted into the vacuum chamber for vacuuming to remove the bubbles inside the mixture. After vacuuming, the temperature of the vacuum chamber is increased to 75°C and the substrates are left inside the chamber for 1 hour. After the soft lithography, the PDMS elastomer layer is carefully lifted off from the petri dish and cut into segments. Isopropanol (IPA) is used to soften the PDMS layer to ease the lifting of the layer. During the stirring of PDMS and curing agent, the PDMS is cured through organometallic crosslinking process. The curing agent for PDMS contains a proprietary platinum-based catalyst that activates the addition of the SiH bond across the vinyl groups in order to form the Si-CH₂-CH₂-Si linkages. The PDMS base oligomers which contain vinyl groups will have at least 3 silicon hydride bonds each after curing process. The

advantage of curing process is that there will be no byproducts such as gas or water after reaction. In other words, there will be no waste generated. It is recommended to set the ratio of PDMS and curing agent at 10:1. Addition of the excess curing agent will cause the PDMS elastomer to be harder and poor elasticity. The patterned PDMS is bonded with glass in this process steps. Both the glass and the patterned PDMS pieces are inserted into plasma preen system and exposed to oxide plasma for 45 seconds. Upon the exposure, a piece of glass slide is attached onto the patterned side of PDMS. The glass slide will be bonded tightly to the PDMS and create permanent sealing.

Results and Discussion

The implementation of the glass slide in the fabrication process possesses several advantages, such as the cheap cost and the ease of observations from the back side. However, the patterns created on the glass slides cannot withstand the soft lithography process in long term. The patterns will be torn off after undergoing several times of soft lithography. The adhesion of SU8 photoresist to glass slides degrades with time. Hence, silicon wafer is used as the substrate for creating the mold. During the photolithography process, in order to create patterns with high similarity to the mask, the gap between the mask and substrate with SU-8 layer has to be very small. SU-8 layer is thicker and stickier compare to other photoresist, Fig. 2 and 3 the fabricated master mould showing inlets and chamber resepectively.

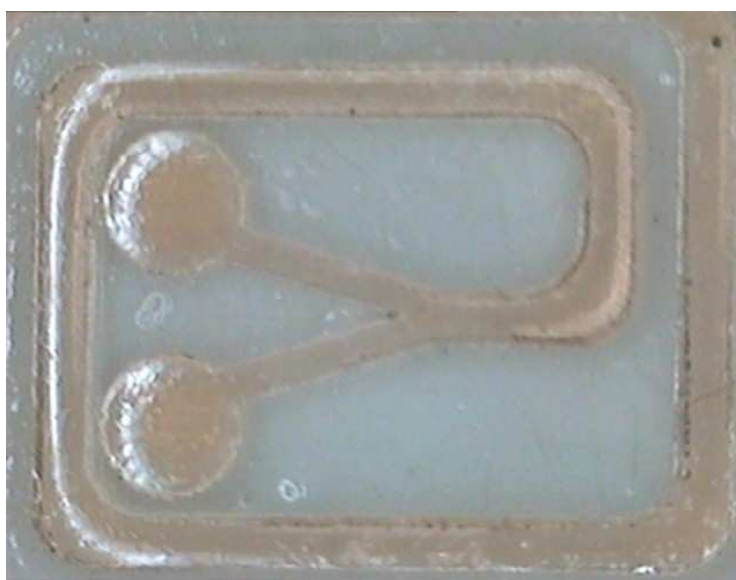


Fig.2, Fabricated master mould showing two inlet



Fig.5, Fabricated master mould showing two micro channels chamber

Any contact of the layer with other surface will leave the vestige of the surface. To overcome the problem, the soft bake and cool down duration has to be increased to 30 minutes and 15 minutes respectively. Upon the increased time of soft bake, the SU-8 layer is hardened and the gap between mask and substrate can be minimized without worrying the sticking problem. As the hardness of the SU-8 layer increasing, the difficulty of create patterns increase in proportionality. The development time has to be increased as well. During the soft lithography process, in order to produce the optimized quality of elastomer, the ratio of PDMS and curing agent is 10:1. Varying the ratio of mixture for PDMS and curing agent will affect the quality of the hardened elastomer. If curing process is undergone with the ratio of curing agent to PDMS less than 1:10, the PDMS cannot be fully cured and the elastomer formed is soft or liquefied if worse. If the ratio of curing agent to PDMS is increased to more than 1:10, a harder and more crosslinking elastomer is formed. Simply increasing the ratio after 1:10 will cause degradation to the elasticity of elastomer.

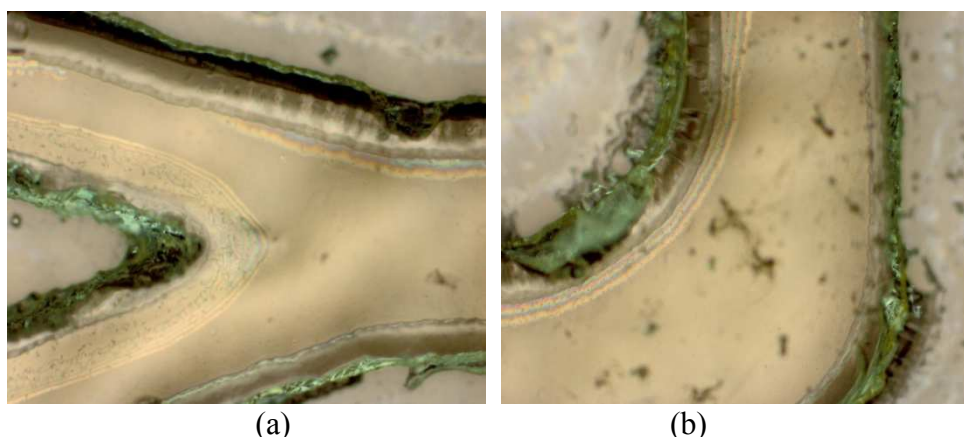


Fig.4, Observation through the microscope on the fabricated micro mixing point. (a) The microchannel short turn angle for enhancing mixing

Two areas on SU-8 molded wafer pieces is studied, that is microchannel and microchamber. Surface analyze are taken and generated for the areas and the measurements are analyzed in 3D form. The results of analysis is as shown in fig. 3. The 3D surface analysis is performed in $0.31\text{nm} \times 0.44\text{nm}$ area on the microchamber. From the observation and analysis in the result, we can conclude that the average height of the microchamber is above 100 micron. The surface roughness is due to the transparency of SU-8 mold on the wafer surface. In overall, the surface of the mold is flat and is capable to produce good patterns of microchamber on PDMS elastomer. From the study of the results, we can observe that the mold has a smooth channel on the wafer substrate. The average height of the microchamber is above 150 microns.

Summary

The fabrication process of the microfluidic mixer is demonstrated. Mixing is the process by which uniformity of concentration is achieved. Depending on the context, mixing may refer to the concentration of a particular component or set of components in the fluid rapid and controlled mixing is essential for studying reaction kinetics with much better time resolution as compared to microscale techniques. Hence, The fabricated Microfluidic mixers are thus integral components essential for proper functioning of microfluidic devices for a wide range of applications.

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