

Low Cost Fabrication of Passive Microfluidic Devices

Alireza Bahadorimehr, Yunas Jumril, Ille Christine Gebeshuber, Chang Fu Dee, Burhanuddin Yeop Majlis
Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, Malaysia
E-mail: burhan@ukm.my

Abstract-This paper presents a low cost method for fabrication of microchannels on glass substrates for microfluidic devices applications. The channels with the depth up to 150 μm can be achieved by implementing a typical photoresist and wet etching process without any complicated deposition methods such as CVD, evaporation or other sophisticated techniques. In particular, AZ5214 photoresist is for the first time introduced for glass etching mask which can strongly resist against etchant attacks up to 2 hours, showing high accuracy for fabrication of microfluidic microchannels. The width of the channels is determined by the width of the lines in photo-mask design and the etch rate of the substrate because of glass isotropic etching characteristics. In practical the channel width range about 30 μm to 350 μm is attainable. Commercially available inexpensive microscopic slides have been used as substrate for etching channels using special etchant solutions. The etch rate of the glass strongly depends on the concentration of the etchant. Achieving smooth and clear surface after wet etching process is an important factor for easily flowing fluid through channels and monitoring purposes. A mixture of different solutions with special ratios has been applied to achieve smooth and clear surface of the etching regions. Two different bonding techniques, optical UV curable glue, and glass-PDMS-glass methods for adhering the etched glass substrate and non-etched glass cover is applied. A novel method for packaging, tubing and fittings for microfluidic devices using PMMA has been presented without the need for any drilling process.

I. INTRODUCTION

Microfluidic systems have become increasingly well-known in different fields of studies. In recent years so many new commercialized microfluidic products has been emerged in the market. Microfluidic devices are going to become one of the most dynamic part of the BioMEMS technology trend. The main applications of microfluidics are medical diagnostics, genetic sequencing, chemistry production, drug discovery, and proteomics.

Depending on applications and suitability, different types of materials can be used as the substrate for the microchannels such as silicon [1], glass [2,3], SU-8 [4], polydimethyl-siloxan (PDMS) [5] and Poly methyl methacrylate (PMMA) [6]. In terms of cost and simplicity, commercially available microscopic slides have been used in this paper.

Numerous fabrication techniques for microfluidic devices have been reported. Fabrication of microchannels as main parts of the microfluidic systems plays an important role in operation of the entire system. Different techniques can be utilized for fabrication of microchannels. SU-8 as a low cost negative resist is a famous material to make vertical and high aspect ratio structures. Using SU-8 as a master mold and pouring PDMS on master is another well-known method for microchannel fabrication. Microchannels with vertical and

precise walls can be achieved using DRIE on different substrates [7,8]. Despite all the techniques, wet etching process is still used as a low cost and simple method for fabrication of microfluidic devices. However, various masking techniques are implemented to make a microchannel via glass substrate. Different sacrificial layers as etch masks for chemical wet etching of glass have been reported. These methods use different materials such as Cr [9], Cr/Au [10,11], polysilicon [12] to deposit a layer as a mask on glass in order to make an open region for wet chemical etchant by different deposition methods such as CVD, LPCVD [12] or other methods which needs special clean room instruments. The method in this paper includes coating the glass surface with a typical photoresist, AZ5214, by spinning the sample on a spincoater, and post baking procedure of photoresist followed by immersing the glass in an etchant with special concentrations of Hydrofluoric acid (HF), Ammonium Fluoride (NH₄F), Hydrochloric acid (HCL) and DI water in a magnetic stirring bath. HF-based methods [13] usually result in a rough surface, but the special recipe consisting of HCl, Buffered Oxide Etchant (BOE) and D.I. water provides a smooth surface [14]. In particular, using AZ5214 photoresist as a mask is for the first time introduced for glass etching instead of common lithography patterning purposes.

Bonding techniques is a significant stage in fabrication of microfluidics devices. Anodic bonding is one of the oldest bonding methods in MEMS for silicon to glass bonding applications, however without any intermediate layer, glass-to-glass cannot be bonded anodically [15]. Thermally bonding is a famous bonding technique for glass-glass bonding [16], however, the high temperature annealing step is difficult to control and may damage the electrical properties of any heat-sensitive layers in microfluidic chip (about 600°C). Another bonding method uses UV glue to adhere two glass surfaces together with clogging effect challenges [17]. Glass-PDMS-glass bonding also has been used for bonding purposes [18,19]. In this paper, two different bonding techniques were utilized to achieve acceptable bonding strength.

Packaging techniques for microfluidic devices has been investigated in numerous researches [20-22]. Most of these researches focus on the polymer based microfluidic systems and usually these techniques require expensive instruments for making an appropriate packaging and fittings. In order to reduce the cost of packaging, commercially available acrylic sheets were used as the frame and package for the microfluidic device assembly. This type of packaging causes elimination of drilling holes on the glass for input and output

connections for tubing purposes. In normal procedures using ultrasonic or conventional drilling is necessary for making holes in glass substrates.

II. EXPERIMENTAL DETAILS

A. Cleaning procedure

The fabrication process starts with the glass substrate cleaning by ultra-sonication in acetone and methanol for 10 min respectively. Subsequently the glass substrates were boiled in piranha solution ($H_2SO_4:H_2O_2= 3:1$) for 15 min. The slides were then immersed in deionised water for 5 min and blow drying with nitrogen gas was applied later. Finally, the cleaned glass substrates were put in a conventional oven for 20 min at $85^\circ C$ to demoisturize.

B. Photolithography and post-baking

Photolithography is a very important process due to attain to the desire thickness of photoresist after spin coating, UV exposure time, and hard baking temperature to achieve the maximum adhesion between photoresist and substrate. In order to accomplish these conditions AZ5214, a positive photoresist, was utilized. Coating was obtained by spinning for 5 seconds at 500 rpm, followed by spinning for 20 seconds at different speeds to compare the results. The photoresist layer was soft baked on a hotplate at $100^\circ C$ for 10 min, resulting moisture-free surface, allowing contact mode exposure. The dried photoresist was UV-exposed in a mask aligner at the wavelength of 365nm in hard contact mode for highest precision purposes. Immediately, after exposure the resist was subjected to a post-exposure bake on a hotplate at $100^\circ C$ for 3 min for adhesion promotion. Development was done in diluted AZ400k developer (DI water: AZ400k = 3:1) at room temperature with a development time of 3-4 min and rinsing in DI water subsequently. A post-bake at $160^\circ C$ for 90 min were applied on a hotplate in order to harden the photoresist against attacks of etchants.

C. Etching process

For producing microchannels a wet etching process was performed. The proper mixture of etchant concentrations can be greatly enhanced the resistant time of photoresist and etch rate as well. First, 10 parts of saturated NH_4F solution was mixed with one part of 49% HF to form 10:1 BOE solution. HF-based etches usually result in a rough surface. However, by adding HCL to BOE solution, a smooth surface is attainable. The ratio of the BOE solution and HCL was 5:1. Putting the coating glass in this solution with magnetic stirring was lead to early attack on some parts of photoresist just in less than 10 min. To overcome this problem, DI water was used to dilute the solution. By adding 100% DI water to the solution, the resistivity time of the photoresist was increased up to more than 2 hours.

For removing photoresist from the glass surface, ultrasonic agitation in acetone was used for 10 min. Subsequently, the same procedure as stated in cleaning procedure section for cleaning etched glass for bonding purposes were performed.

D. Bonding with UV curable glue

The method involves UV curable glue that can be used for glass microfluidic chips bonding at room temperatures. The use of UV-curable glue was found to be a quick, easy, and

inexpensive method for attachment of glass substrates together. The glue with low viscosity which ensures formation of a thin layer after spinning was selected. To avoid filling the fluidic channels with the glue a stamping method was utilized.

Another clean microscopic slide was used for stamping procedure. A thin layer of UV glue was applied on this slide by spinning it at 4000 rpm for 20s. The etched glass slide containing the microchannels was then brought in contact with the glue surface of the plain slide to transfer the glue to the non-etched regions of the microfluidic slide. In next stage, two glass slides can be selected to permanently adhere to the microfluidic slide.

E. Glass-PDMS-Glass Bonding

The microfluidic glass slide can be bond to another plain slide using three-layer glass-PDMS-glass structure. A curing agent and PDMS prepolymer (SYLGARD 184 Silicone Elastomer Kit, Dow Corning, Mid- land, MI) were thoroughly mixed in a 1 : 10 weight ratio and then were put in a conventional silica gel desiccator for 1 hour to remove the air bubbles in the PDMS generated during mixing procedures. PDMS was then poured over the surface of the non-etched slide and spun at 3500 rpm for 20 s and soft baked at $70^\circ C$ for 30 min to produce a thin membrane. In this stage the PDMS is still sticky [18]. Then, the microfluidic slide was bonded to the PDMS membrane with its own weight. After that, the glass-PDMS-glass structure was cured at $150^\circ C$ for 15 min.

F. Packaging

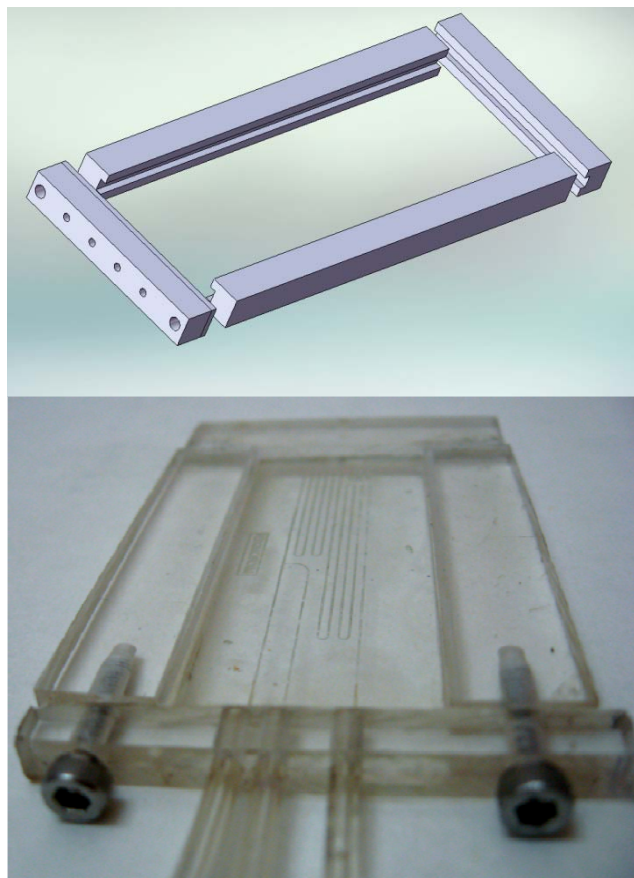


Fig. 1. (a) Schematic and (b) design of frame for microfluidic device

Acrylic sheets have the advantages of transparency, cheap and compatibility with so many milling machines and common drilling using typical drill bits or end mills for making holes or patterns. Using a common milling machine the slots with 2mm width and 1mm depth was milled through an acrylic substrate to make a slot for microfluidic device to move in and out easily such as a cabinet drawer (Fig. 1a). A PDMS molding technique was used for quick and reliable

connection is guaranteed.

III. RESULTS AND DISCUSSION

Microscopic glass slides with easy accessibility were used as main material to fabricate the entire microfluidic chip. The standard glass slides with 25mm×75mm and 1mm thickness were utilized. Hydrophobicity/hydrophilicity of microchannel surface is an important factor for different microfluidic applications. For instance, the differences in the reaction of hydrophilic and hydrophobic surfaces with blood proteins and cells have been considered in some researches [23-26]. The glass slides are naturally hydrophilic and the microchannels were made by etching process showed the same behavior (contact angle with water 18–20°). However, by some treatment methods such as methylation of the clean surfaces by incubation in 0.1% 1, 1, 1, 3, 3, 3-hexamethylsilazane in dichloromethane [27], coating the channels with octadecyltrichlorosilane (OTS) [28], dielectric barrier discharge [29], hydrophobic surfaces can be achieved.

AZ5214 is a thick positive photoresist which was coated with different speeds on glass substrates (600, 700, 800 and 900 rpm). The optimum thickness was determined to be about 7 μm in 700 rpm in order to withstand the attacks of etchant solutions for up to 90 min. Different baking process was used in this work. The primary purpose of baking is to removing moisture from the photoresist in order to avoid adherence of photoresist to the mask in mask aligner (prebake) and increase the surface adhesion (post-bake). In addition, heating affects on photoresist compounds to become a non-photosensitive product by changing chemical characteristics of photoresist. This can affect on exposure time too. Therefore, determining temperature and heating time have significant impacts on accuracy of the design. Different heating temperatures were studied in order to optimize the photoresist patterning process for subsequent etching process. After photoresist spin coating on glass, the substrate was put on a hotplate at 100°C for 10 min. Subsequently after UV exposure the coated substrates were put on a hotplate for 3 min at 100°C for prebake procedure. Post-bake process was performed after developing the exposed regions at 160°C for 90 min on a hotplate.

The wet etching process was performed in a plastic container using magnetic stirring plate. Different mixtures of NH₄F/HF/HCL/DI water were studied in order to achieve to a acceptable etch rate, smooth microchannel surface, no underlying glass etching effect, and clear glass slide in all regions without any signs of damages. Etching the glass can cause undercutting effect. Due to this effect width of the channels increase compare to the mask design. In order to compensate for undercutting effect of isotropic etching, determining glass etch rate is an important factor.

We used scanning electron microscope (SEM) for etch rate measurements. Fig. 2 illustrates the depth of about 150μm after 90 min of etching using diluted etchant. Fig. 3 presents a microscopic view of the effect of etchant concentration with a diluted etchant and without dilution. It shows that the edges of the microchannel walls are not sharp when a non-diluted etchant was applied in comparison with the diluted

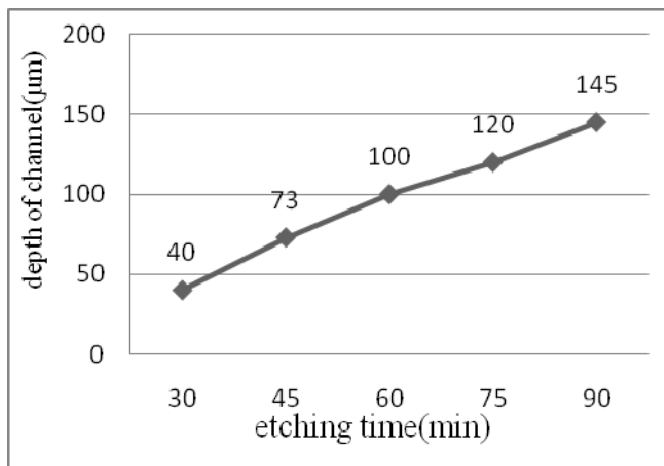


Fig. 2. Depth of channel vs. etching time

connections of tubings to the microfluidic device without using typical chromatography and column fittings. PDMS was used for sealing purposes between acrylic frame and glass microfluidic device. It led to low dead volume, fast connection and disconnection, and low cost fabrication of entire frame for most types of microfluidic systems. By tightening the screws in both sides of the connector a reliable

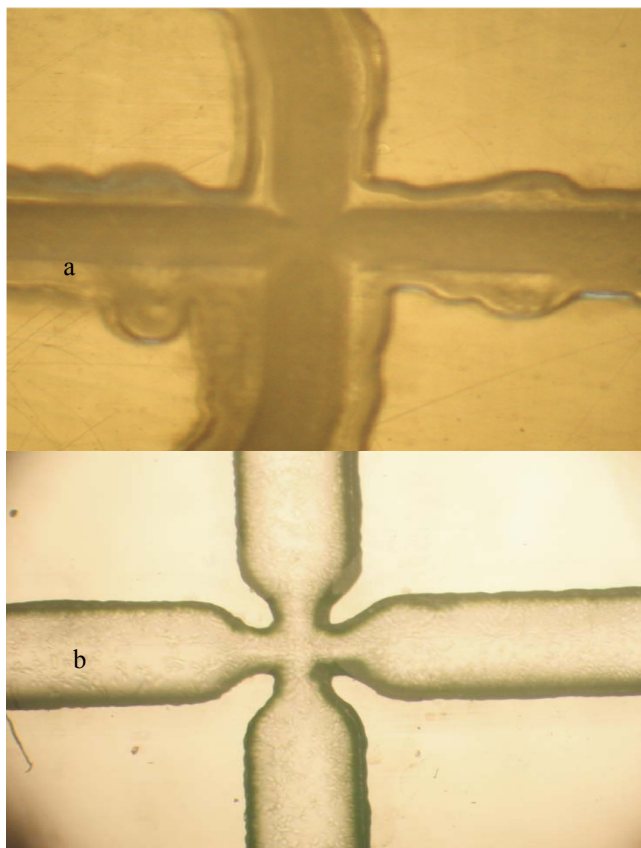


Fig. 3. Effect of the (a) non-diluted and (b) diluted etchant on side walls

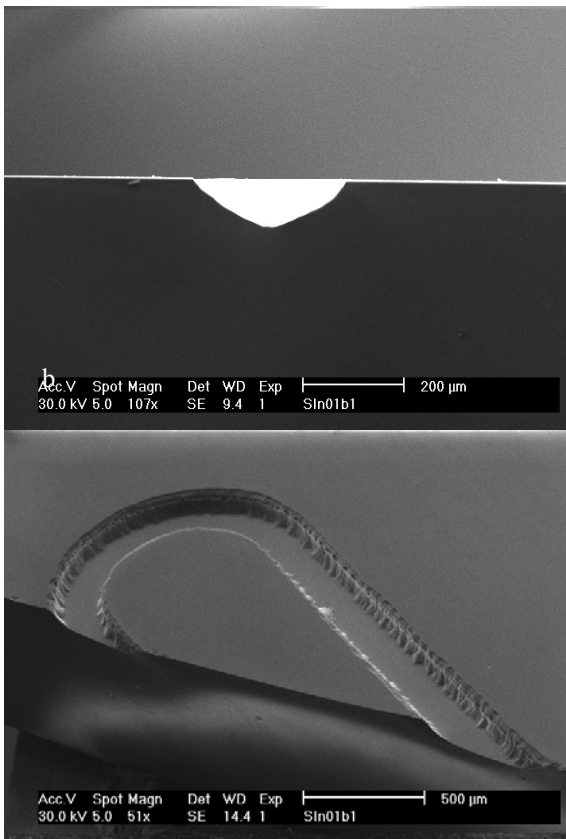


Fig. 4. SEM cross section view (a) and an angle view (b) of the microchannel

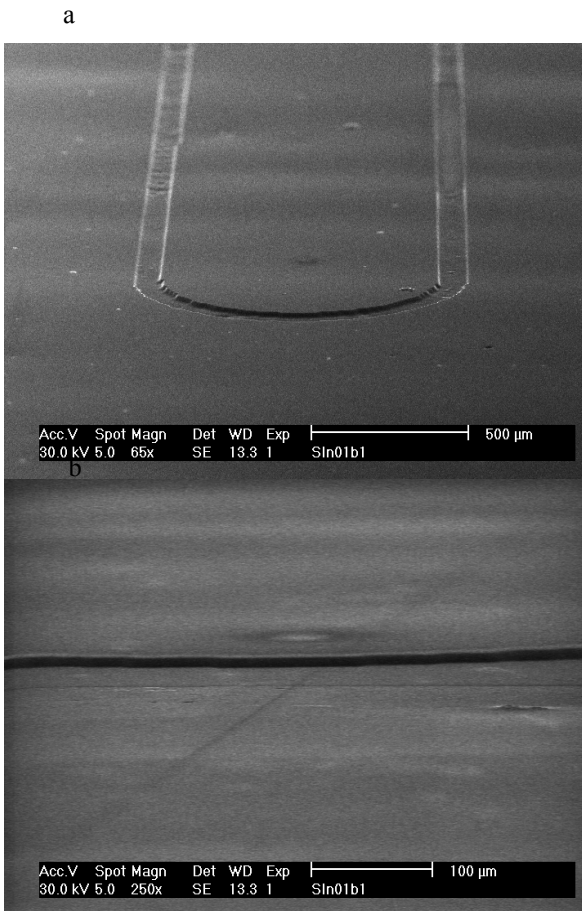


Fig. 5. SU-8 on glass with (a) 70μm thickness and (b) 40μm thickness vertical walls

etchant. The dilution ratio was 2 part of DI water to 1 part of

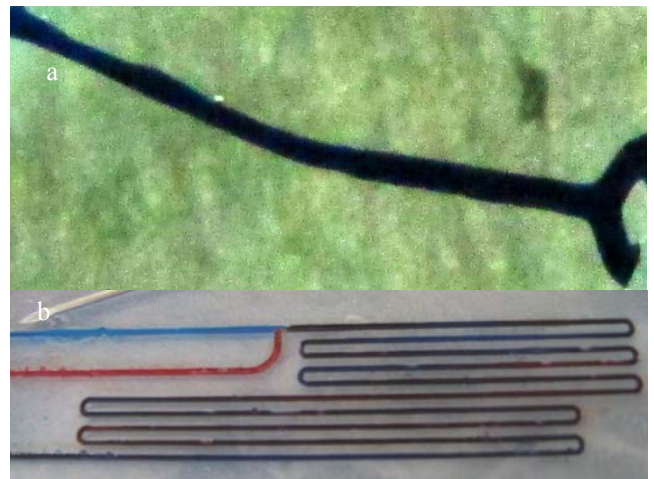


Fig. 6. UV glue bonding (a) and PDMS bonding (b) by manually filling the microchannels with dye water

BOE: HCL=5:1.

Fig. 4 shows the SEM view of a microchannel after 40 min wet etching. As can be seen the sharp edges and approximately smooth surface was achieved. In addition SU-8 was used to fabricate microchannels on the glass. We used the same glass substrate for spin coating the SU-8 and typical process for SU-8 photolithography and curing. The results are shown in Fig. 5. In comparison with glass channels the edges are sharper and vertical channels are attainable.

The bonding was applied using UV glue, glass-PDMS-glass methods. The results for UV glue are shown in Fig. 6a by filling the channels with dye water. This figure illustrates no penetration of dye water to other areas after sequential experiments. Fig. 6b illustrates a microfluidic micromixer for mixing two liquids together in nanolitre orders using PDMS bonding.

IV. CONCLUSION

In this paper we presented a simple and cost effective fabrication method for making micro-channels using in microfluidic devices. This method uses typical microscopic glass slides as a substrate for fabrication of micro-channels. Using photo-resist as a mask led to gain precise results instead of other deposition methods which need sophisticated procedures and instruments. A smooth channel surface with acceptable sharp wall edges was achieved using specific etchant solution. In addition, the comparison between the channels using wet etching procedures and SU-8 techniques was discussed. Two different glass to glass bonding was introduced. The UV glue and PDMS between two glasses were used to achieve promising bonding results. A new and easy packaging and fitting technique was proposed using acrylic sheets and PDMS.

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