Abstract — This paper reports a novel method to fabricate microstructures under room temperature, which could be used in microfluidic system. This microfluidic system can be used to automatically transport liquid by evaporation at the end without any external driving force. Because the microfluidic system chip was easy to be fabricated, and it didn’t need dynamic temperature control system and driving pump, the cost of whole system would be cheap. Moreover, silicon dioxide is easy to integrate with other system by semiconductor technology. Therefore, it is a high economic technology to be applied on commercial products.

Index Terms — microfluidic system, evaporating force, microchannel, silicon dioxide.

INTRODUCTION

In the past decade, there has been an explosion of interest in the field of microfluidics [1-10]. Material selection and corresponding fabrication procedures are two important challenges in developing microfluidic devices. At the present time, most microfluidic devices are made from silicon [1, 3, 7, 9] or glass [2, 4-6, 8, 10], because it has many advantages, such as flat surfaces, good electric insulation, and excellent optical properties. MEMS technology can be implemented using a number of different materials and manufacturing techniques. Recently, researchers are expecting disposable plastic devices by polymer materials [11-16]. It is hard to integrate a complex microfluidic system with simple processes, which would reduce yield and increase cost. Thus, to combine glass and polymer would be a proper choice on developing microfluidic system.

Silicon is the material normally used to create most integrated circuits in consumer electronic world. Several advantages, availability of cheap high-quality materials and ability to incorporate electronic functionality, make silicon attractive for a wide variety of MEMS applications. The basic techniques for producing all silicon based MEMS devices are deposition of material layers, patterning of these layers by photolithography, and etched to generate the required shapes.

Even though the electronics industry provides an economy of scale for the silicon industry, crystalline silicon is still a complex and relatively expensive material to be used on biomedical applications. Under recent development, polymers would be a good choice, which could be produced in huge volumes and with a great variety of material characteristics. MEMS devices can be made from polymers by several processes, such as injection moulding, embossing, or stereolithography, which are especially well suitable on microfluidic applications.

Microfluidic systems usually need external force like micropump or wetting effect, to drive liquid inside microchannel. In this research, to apply natural force, evaporating force, in microfluidic system could give it several advantages. Thus, the motivation for this research is to develop a novel fabrication process under room temperature by using glass and polymers. The detailed will be described as follows.

WORKING PRINCIPLES

Many of continues-flow microfluidic system were developed by different materials, like SU8, PDMS, glass, or silicon. However, most polymers are hydrophobic, which needs to be treated as hydrophilic by using special techniques. Silicon dioxide has hydrophilic property that was stable and it is thus preferable for applications in which devices are used extensively, such as in high throughput screening. SiO2 was also known for its superior optical properties, useful for optical detection and analysis methods. Furthermore, the auto fluorescence in glass is considerably smaller than the one in most polymer materials. Moreover, silicon dioxide is easy to integrate with other system by semiconductor technology [17]. By applying evaporating force for liquid transporation, how to using silicon dioxide to fabricate microchannel under room temperature would be the main issue in developed microfluidic system?

The microfluidic system was designed as shown in figure 1(a), including sample inlets, particle separation region, and evaporation regions as shown on figure 1(b).

The driving force was generated by liquid evaporation at the exit of microchannels controlled by heaters. Lots of heater design was used to accumulate the generated force by liquid evaporation. The force could be estimated by using following equation:

\[
\Delta F = \frac{P_1 - P_2}{\gamma} \Delta H_v
\]

(1)

where \(P_1, P_2\) are the vapor pressures at temperatures \(T_1, T_2\) respectively, and \(\Delta H_v\) is the enthalpy of vaporization. The rate of evaporation in an open system is related to the vapor pressure found in a closed system. However, in an opened system, it can be only estimated by experiments from plants, as followed equations.

Da-Jeng Yao is with the Institute of MicroElectroMechanical System, National Tsing Hua University, Taiwan. (Email: dyao@mx.nthu.edu.tw)

Po-Yu Chen is with the Department of Engineering and System Science, National Tsing Hua University, Taiwan. (Email: boypatrick.tw@gmail.com)
where $R_{eva}$ is evaporation rate, $M$ is molecular weight, $J$ is the vapor pressures at temperature 300K. In order to verify and improve this conception, the simple experiment was designed.

VERIFICATION

Microchannel with different area of evaporation region was designed, as shown on figure 2(a). Instead of heater design, external thermal source was used on the top to change temperature at the outlet of microchannel for liquid flowing inside. Generally, the width of comb was usually smaller than the width of main channel, to ensure that liquid will be trapped on the end of microchannel.

Different ratios of width between main channel and evaporating region were patterned onto wafer, then anisotropic etching by KOH. The silicon wafer and glass wafer were cleaned in RCA-1, then piranha solution at 95°C. The cleaned wafers were rinsed by de-ionized (DI) water and dried by pure N₂. It is observed that the chemical cleaning causes the surface of both silicon wafer and glass wafer become hydrophilic. The contact angle has been reduced from 40° to almost 0° before and after cleaning. After cleaning, anodic bonding was used to bond silicon wafer and glass wafer at 600UV under 400°C, and bonding time was around 10 min. After processing, evaporating region of chips was fixed on silicon bulk which was put on top of hot plate to keep on the same temperature, is shown on figure 2(b).

As results, velocity of flow was proportion to area of evaporating region. It is linear relation since operating on fixed width of main channel with different area of evaporating region. The slope of velocity/evaporating-area ratio will decrease with width- increasing of main channel.

FABRICATION PROCESS

Glass has material properties that are stable in time and it is thus preferable for applications in which devices are used extensively, such as in high throughput screening. For products that need a reliable shelf life glass is a good material to work with. It is also known for its superior optical properties, useful with optical detection and analysis methods. Fused silica offers transparency down to UV wavelengths. Furthermore, the auto fluorescence of glass is considerably smaller than of most polymer materials.

Glass is hydrophilic, meaning it attracts and holds moisture. Most plastics, in comparison, are hydrophobic and need treatment to become hydrophilic. If hydrophobic surfaces are needed, we can modify the glass surface by applying a coating to the channels.

In this process, photoresist AZ9260 was used as sacrificial layer, which is easy to be deposited and patterned. Another important issue for this developed process is to deposit porous
silicon dioxide film by e-beam evaporator, which degree of porosity could be controlled by adjusting deposition rate. By using this porous property, organic solution can go through silicon dioxide thin film to release structure and to form microchannel.

The process flow of microfluidic system was shown on figure 3 [18]. Glass wafer were cleaned in RCA-1 and piranha solutions at 95°C. The clean wafers were rinsed with de-ionized (DI) water and dried in pure N₂. Then glass wafer was coated by HMDS to improve the adhesion between PR and wafer. First, we patterned AZ9260 photoresist, which was coated with 3000 rpm and exposed under 200 mJ. Then, photoresist was treated up to 110°C for 60 seconds to be reflowed. Secondly, silicon dioxide/Ti (10000 Å /1500 Å) was deposited by e-beam evaporator on top of PR and glass substrate. The deposited structure was strong enough to make etching solution penetrate to release PR and to form microchannel. The heaters was deposited and patterned at the entrance and exit by RIE etching. The percentage of oxygen in RIE etching process is very important. The high percentages of oxygen will generate too much oxygen ions to damage PR and metal. If less oxygen ions exist in chamber, organic residue will not be removed from surface of wafer. Then, microstructures were easily released by acetone or some organic solvent through porous SiO₂ structures.

RESULT AND DISCUSSION

Figure 4(a) and 4(b) are top view of microchannel with heater at the outlet of microfluidic system. It shows that fabrication process was easy to integrate metal onto microchannel structures. The most important is that microchannel structures were fabricated by porous silicon dioxide. Compared with other fabrication method, like MUMPs or polymer fabrication process[19], this novel fabrication would be adoptable for microchannel fabrication. Moreover, the whole fabrication process was down under room temperature, which is suitable for bio-medical application if bio-related layer was coated in the middle of device fabrication.

Figure 4: (a) Evaporating design on microfluidic system, SEM pictures for (b) heater and temperature sensor, and (c) entrance of microchannel

In figure 4(c), on the top of microchannel forms curvature at the sidewall of microchannel, that is clearly shown successful microchannel formation after releasing without damage.

However, it has some unavoidable limit of channel size to release successfully, including proper height and width of microchannel. From the results, the maximum height can be reached up to 7 μm and the width can be created up to 60 μm, if 1 μm thin film of silicon dioxide was deposited as structure material. Release temperature also plays an important role. High temperature caused solvent boiled in the microchannel, and vapor of solvent would rapidly create expansion to damage microchannel structures, shown on figure 5. The crisp thin film, broken by vapor of solvent, was
trapped in microchannel.

Figure 5: Thin film of silicon dioxide was broken by expansion of vapor. Thin film was trapped in the sidewall of microchannel.

After microchannel formation by developed fabrication process, microscale of particles, accharomycesets, were used in microfluidic system to prove the liquid transportation by evaporating force. By turning on the heater at exit of microchannel, the evaporation force would drive the liquid, as shown on figure 6. The particle movement is steady with time. Each photo was taken every 0.28 seconds, and total moving length is about 0.18 µm. By observing the movement of particles, velocity of saccharomycetes was estimated up to 500µm per second on controlling heater temperature at about 40°C.

Figure 6: Movement of saccharomycetes in microchannel by evaporating force

CONCLUSION

In this paper, a novel method to fabricate micro structures under room temperature was reported, which could be used in microfluidic system. Evaporating force used in the system to drive liquid was proved. Because silicon dioxide is easy to be integrated with other system by semiconductor technology, it is a high economic technology to be applied on commercial products. By integrating other designs in system like electrode and filter, particles can be controlled easily in the future.

ACKNOWLEDGMENT

The authors would thank Micro-/Nano- Bio-Opto-Electro-Mechanical System and Fluidic LAB, ESS (NTHU, Taiwan).

Without their fully support, the experiment would not be measured at the early stages of this research.

REFERENCES