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Investigation of Simple Process Technology for the Fabrication of Valveless Micropumps

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Abstract This paper presents a simple process technique for the fabrication of valveless micro-pumps. The process design utilizes standard MEMS process using double-sided anisotropic silicon wet etching process with an additional adhesive bonding technique. The diffuser and nozzle element of the pump with depth of 50 µm, as well as a 150 µm thick silicon membrane are designed and fabricated using only 3 patterning process steps. A piezoelectric plate working at the frequency range from 0.1 kHz to 2 kHz is bonded on to the back side of the silicon membrane to create the membrane actuation. The patterning process of thick photoresist used as the adhesive layer for the substrate bonding is also discussed in detail. The fluid flow is observed and the process reproducibility is proven which show a good prospect for the future development of miniaturized valveless pump for biomedical application.

Introduction

Micropumps are essential components of the miniaturization of fluidic systems to enable injection and control of fluid flow in a variety of applications, such as integrated fluidic channel arrangements in chemical analysis systems, electronics cooling, as well as for drug delivery systems.

Micropumps offer important advantages because they are compact and small in size [1-3] and provide precise dosing and rapid response time. It is thus very useful in biological micro-systems where small sample consumption and rapid analysis are considered [4]. In this study, a simple process for fabricating valveless micropumps is presented. The fabrication method presented in this study enables us to fabricate micropump structures in an efficient way. The fabrication process involved in this work is straightforward, demanding only standard MEMS process.

Pump Design

The micropump consists of a piezoelectric actuator (piezo-plate), a silicon membrane, a pump chamber and diffuser/nozzle elements (Fig. 1). The resulting size of the pump system is 22 mm x 8 mm. The piezo-plate is 5 mm x 5 mm x 600 µm in size residing in a chamber at the back side of silicon substrate. The membrane acts as the movable mechanical part enabling pressure changes in the chamber. The diffuser/nozzle elements are constructed planar on the top side of silicon substrate. Maximum diffuser efficiency highly depends on the geometry of the diffuser/nozzle elements. Therefore, neck angles of 15^0 are chosen in this study, with neck width at 200 µm and the length of 1400 µm.

The fluid flow is affected by the continuous vibration of the membrane which is influenced by the driving voltage and signal frequency applied to the piezo-plate. Hence the pumping mechanism is realized through the mechanical push- and pull activities of the piezo-material to the membrane.

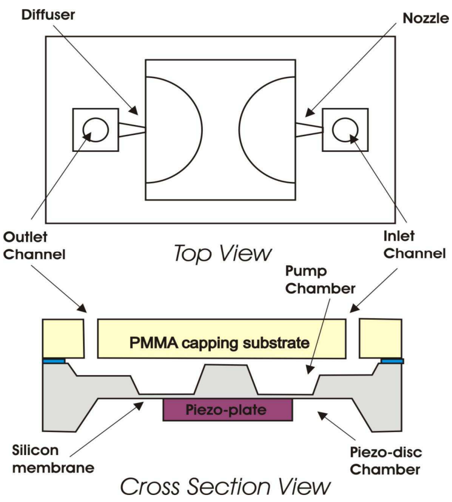

Fig. 1. Schematic design of PVLMP (Planar Valveless Micropump)

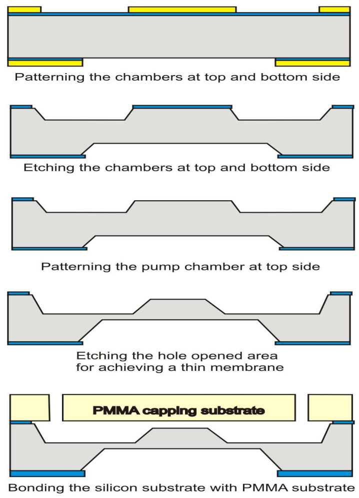

Fig. 2. Schematic fabrication process of valveless micropump using double-sided etching

The optimized geometrical dimensioning for the micropump was obtained from our previous work [5-6]. The pump was simulated part-by-part separately, i.e. fluid part and structure part. Fluid parts are the pump chamber and valves while the structure part is the actuating membrane layer with the piezoelectric-plate glued on top of the silicon membrane as actuator material. The system is then constructed with the optimized dimensions.

The Process Flow

Commercially available PMMA material and <100> silicon are used as capping and pump materials, respectively. The silicon substrate is 650 µm thick coated on both sides with a 200 nm silicon nitride layer. An 800 µm thick PZT material made of Pb(ZrTi) Ox (lead titanate zirconate) is used as actuator material and glued on to the silicon membrane using conductive epoxy material.

The bond material is made of thick film photoresist AZ4620, that is patterned on PMMA material prior to the bonding process. The photoresist pattern is produced by UV light exposure for 60 seconds, and followed by developing in AZ400K. These patterning procedures and the resist material were aplied for all patterning process, including resist patterning process for wafer bonding. Another function of the resist AZ4620 is as mask material to define the pattern of piezo-chamber and pump elements.

The detailed fabrication process used in this study is shown in Figure 2. Only 3 optical masks need to be applied for patterning the pump structure on the silicon substrate. Then, a double side anisotropic KOH wet etching process of the silicon substrate is used for creating the structures. Double side mask alignment are therefore necessary because the pump chamber and piezo-disc chamber are etched at the same time which reduces the step processes by 50 %. Fig. 3 shows the etch rate profile of KOH solution for etching <100> silicon substrate.

The result shows that a 35% KOH composition in the solution will achieve an etch rate of about 1 µm/minute. Etching proccess by various etching temperatures is also einvestigated in order to find appropriate surface quality of the membrane. For this purpose, 35% KOH solution are used for etching the silicon at four different etch temperatures, of 65^0C, 70^0C, 75^0C, and 80^0C. The surface roughness is measured using the surface profiler. The effect of etching temperature to the surface roughness and etching rate is displayed in Fig. 4. The results show that the increase in solution temperature up to 75^0C causes an increase in the surface roughness. On the other hand, etching at 80^0C results to a better surface quality. It is also shown that the atch rate increases with temperature. After creating the pump structures, a piezoelectric plate is then glued on to the silicon substrate by sticking it using conductive epoxy material.

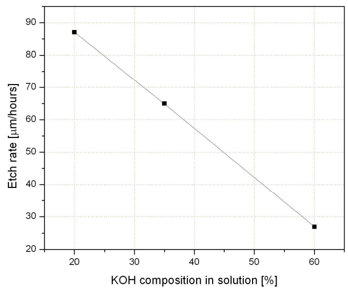

Fig. 3. Etch rate profile of KOH solution for <100> silicon

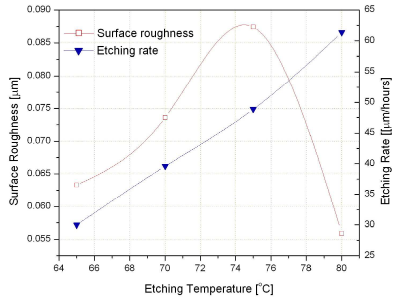

Fig. 4. Surface roughness and etching rate at various temperature

In the final step of the process, the silicon substrate and capping substrate are bonded together to isolate the chamber from environment. Adhesive bonding using thick AZ 4620 resist is used to bond the fabricated pump structures on silicon substrate with PMMA based capping substrate. The bonding has also to consider the allignment of the top and bottom substrate in order to match the position of the pump elements with inlet and outlet channel.

Prior to the bonding process, input and output channel are created on PMMA substrate by drilling the substrate. The input/output channels have the outer diameter of 0.8 mm, enabling the installation of tubing connector to the external ambience. After the channel creation, the alignment pad on the PMMA substrate is patterned by photolithography process. Bonding process is then conducted by pressing the wafers in an adhesive bonding system, as shown in Fig. 5. The two substrates are placed in the system by adjusting the pad position. The glass wafer is transparent hence enable the observation of the pad position. Once the position is aligned, the wafers are pressed together and left for about 24 hours at room temperature to enable a slow sticking between the wafers.

Fabrications results

As mentioned above, the etching of 250 µm deep silicon at each side of silicon substrate is required to achieve a 150 µm thick silicon membrane. For this purpose, first etching at both sides of the silicon wafer for 200 minutes is required to achieve a 200 µm deep chamber. At this point, a 250 µm thick membrane is already produced. The similar process sequence is then implemented for patterning the nozzle/diffuser valves on the top substrate. Finally, all opened area are etched together for 50 minutes. After etching the silicon substrate for totally 250 minutes, a 250 µm silicon trench is properly produced, while a 54.7^{o} angle side slope from the plane is approved and smooth and clean surface are also observed (Fig. 6). As the result, a 50 µm deep diffuser/nozzle, 250 µm deep chambers and 150 µm thick silicon pump membrane are produced (Fig. 7).

Finally, the fabricated pumps elements are bonded with the capping PMMA substrate to protect the pump system with environment. As shown in Figure 8, the structure of the micro-pump bonded with PMMA substrate is successfully fabricated.

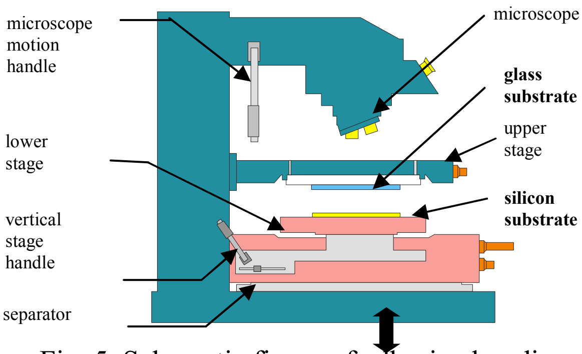

Fig. 5. Schematic figure of adhesive bonding system

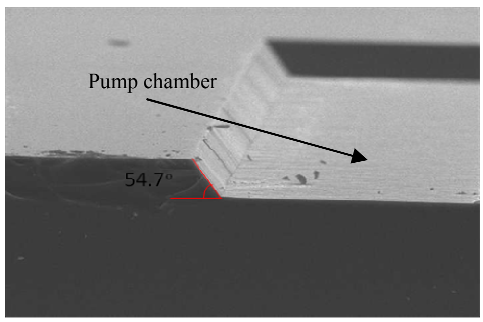

Fig. 6. The fabricated pump chamber with 54.7^{o} wall side slope and clean surface.

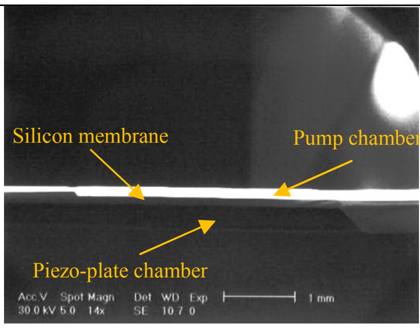

Fig. 7. Cross-section view of fabricated membrane after double sided silicon etching

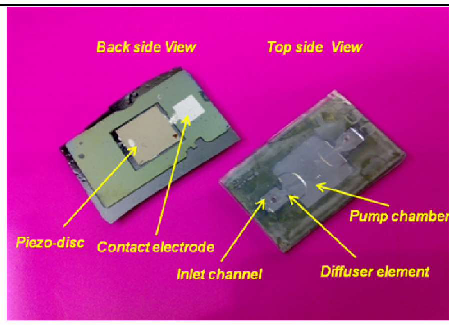

Fig 8. Photograph of fabricated pump at back side and front side

The functionality of the fabricated piezoelectric micropump was tested using DI water as the fluid medium. Two of the most mportant parameters that affect flow rate, namely driving voltage and driving frequency of the micropump were examined. It is observed that by increasing the driving frequency, the flow rate can be increased. The driving frequency however must not exceed the resonant frequency of the membrane. For a driving voltage of 16 Vpp and optimal frequency of 0.673 kHz, the flow rate of 4.98 nL per minute was observed.

Conclusion

A piezoelectric valveless micropump has been designed and fabricated using a simple MEMS process technique. Double-sided etching of <100> silicon substrate using anisotropic wet etching technique was used to reduce the process step. The results show that reproducible and controllable processes are achievable. Due to miniature size and controlled flow rate, this pump is capable of providing high accuracy doses as prescribed in for each individual usage with a net flow rate of 4,98 $nL.min^{-1}$. The work presented here illustrates the feasibility and merits of utilizing simple MEMS process technique for fast and reliable process fabrication of valveless micropumps.

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References

[1] Y. C. Lim, A.Z. Kouzani and W. Duan, Lab-on-a-chip: a component view, Microsystem Technologies 16 (2010) 1995–2015

[2] H.K. Ma, B.R. Hou, C. Yao Lin and J.J. Gao, The improved performance of one-side actuating diaphragm micropump for a liquid cooling system, International Communications in Heat and Mass Transfer 35 (2008) 957–966

[3] F. Amirouche, Y. Zhou and T. Johnson, Current micropump technologies and their biomedical applications, Microsystem Technology, 15 (2009) 647-666

[4] K. Junwu, Y. Zhigang, P. Taijiang, C. Guangming and W. Boda, Design and test of a high-performance piezoelectric micropump for drug delivery, Sensors and Actuators A 121 (2005) 156–161

[5] J. Johari, J. Yunas and B.Y. Majlis, Piezoelectric Micropump for Drug Delivery System Fabricated Using Two Optical Masks, Advanced Materials Research, 74 (2009) 279-282

[6] N. Soin and B.Y. majlis, Development of Perfect Silicon Corrugated Diaphragm using Anisotropic Etching, Microelectronic Engineering, 83, Issue: 4-9 (2006) 1438-1441

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