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Design and Fabrication of MEMS Micropumps using Double Sided Etching

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Abstract—**In this paper, we report a simple technique for the fabrication of planar valveless micropumps. The technique utilizes MEMS fabrication methods by using a double sided etch technique. Instead of using several masks and process steps, an anisotropic wet etch technique at both sides of a silicon substrate is implemented at the same time for creating the pump membrane and the diffuser/nozzle elements. A planar diffuser and a nozzle element of the pump, as well as a 150 μm thick silicon membrane, are designed and fabricated using only three pattern process steps. An actuator-chamber and a pump-chamber with depths of 250 μm are formed after 250 min KOH etching, while the diffuser/nozzle element with a depth of 50 μm are sequentially formed after chamber forming. The process is simple and reproducible which opens the opportunity for fast prototyping of MEMS micropumps.**

Keywords—**MEMS micropump, planar valveless, design and fabrication, KOH etching**

Introduction

Micropumps are essential components of the miniaturization of fluidic systems to enable liquid injection to systems and to control fluidic flow in a variety of applications such as integrated fluidic channel arrangements for chemical analysis systems or electronics cooling as well as for drug delivery systems [1-3]. Micropumps offer important advantages because they are compact and small in size, they can operate using small sample volumes, and they provide rapid respond time [4]. Miniaturized pump systems for chemical and biomedical applications have been widely studied. Various types of micropumps have been fabricated on different substrates such as peristaltic micropumps [5], metallic micropumps [6], plastic micropumps [7], as well as valveless piezoelectric micropumps [8]. Among these types, valveless piezoelectric actuated micropumps have the advantage of moderate pressure and displacement at low power consumption, good reliability, and energy efficiency. They also respond rapidly and are widely used due to their ability to conduct particles without support from interior moving mechanical parts, thereby reducing the risk of clogging [9].

In this study, a simple and fast but reliable process for fabricating valveless micropumps is reported. Planar diffuser elements, known as dynamic passive valves that are structured on a planar surface, are used. The benefits of planar diffuser elements include high flow rates and ease of manufacture using conventional silicon micromachining techniques. The simple fabrication method should enable us to fabricate pump structures in an efficient way. The fabrication process involved in this work is very straightforward, demanding only standard MEMS technologies.

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Design of the Planar Valveless Micropump

The valveless micropump is a complex structure in a coupled fluidic system. The pump system consists of a piezo-electric actuator (piezo-disc), a silicon membrane, a pump chamber, and a microdiffuser/nozzle (Fig. 1). Diffuser/nozzle elements, known as dynamic passive valves, are constructed on a planar surface. The diffuser/nozzle design determines the performance of the micropump. According to the literature [10], the maximum diffuser efficiency depends strongly on the geometry of the diffuser/nozzle elements. Therefore, neck angles of 15° were chosen in this study. A neck width of 200 μm and a neck length of 1400 μm were chosen. The resulting size of the pump system is 22×8 mm^2. The piezo-disc has a thickness of 600 μm and an area of 5×5 mm^2 residing in a chamber at the back side of the silicon substrate. The liquid flow will be affected by the continuous vibration of the membrane, which is influenced by the driving voltage and signal frequency of the piezo-disc.

Fig. 2 shows the relationship between the membrane deflection and the driving voltage when applied to the piezo disc. It is shown that membrane deflection increases with the driving voltage. However, the maximum deflection of the membrane is determined by the membrane thickness. For our design, it is shown that the membrane can be deflected up to 30 μm. The thicker the membrane is, the less flexible it is (Fig. 3). The optimized geometrical dimensioning for the micropump was performed in our previous work by simulating the pump design parts separately, that is, the fluid part and the structure part. The fluid parts are the pump chamber and valves while the structure part is the actuation layer, where the piezoelectric disc is glued on top of the silicon membrane. The system is then constructed with these optimized dimensions [11].

Fabrication Process

In this study, commercially-available PMMA material and (100) oriented silicon are used as capping and pump material, respectively. The silicon substrate is 650 μm in thickness

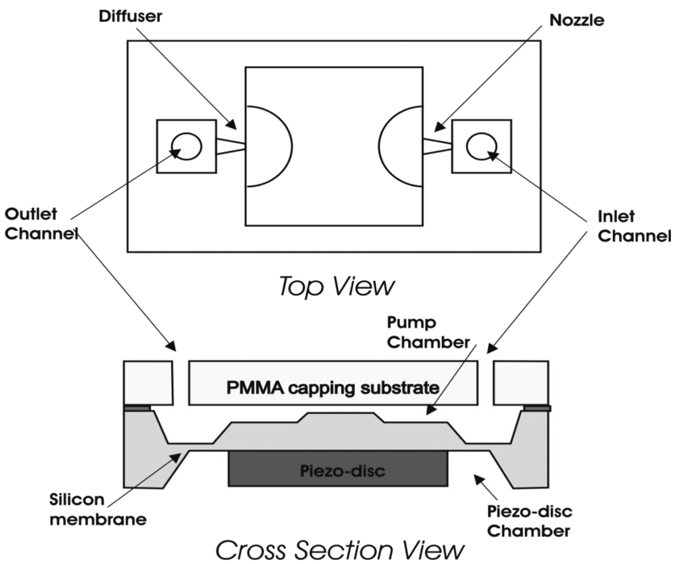

Fig. 1. Schematic design of PVLMP (planar valveless micropump).

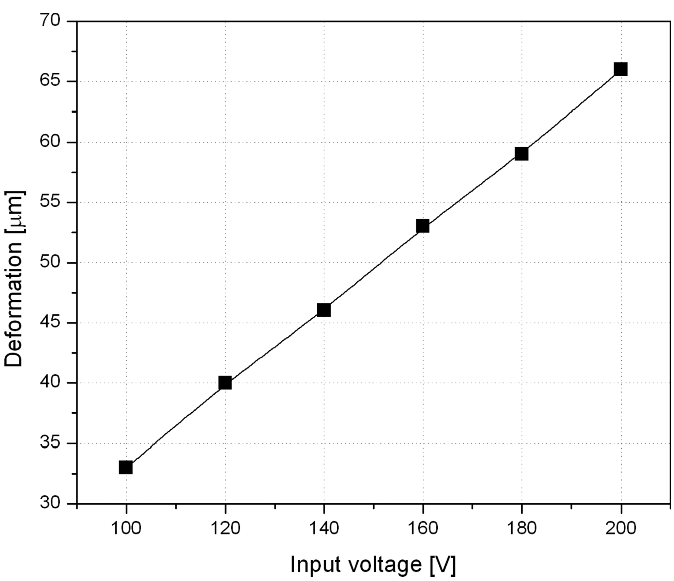

Fig. 2. The relationship between the membrane deflection and the driving voltage.

coated on both sides with a 200 nm silicon nitride layer. The pump membrane and the diffuser/nozzle elements are fabricated using a double-sided etch process, in which both wafer surfaces are etched at the same time. This technique reduces the step processes up to 50%. However, the process requires knowledge of the exact etch rate to ensure the achievable membrane thickness. Only three optical mask patterns need to be applied to the silicon substrate. The detailed fabrication process used in this study is shown in Fig. 4.

The pump structures are created using the double sided anisotropic wet etching process on the first silicon substrate. Double sided mask alignment is therefore necessary because the diffuser/nozzle, pump chamber, and piezo-disc chamber are etched at the same time from both sides of the silicon wafer.

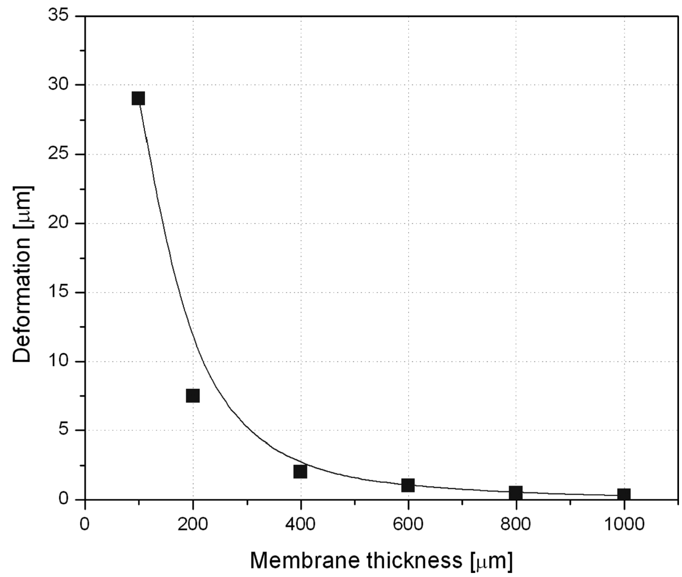

Fig. 3. The relationship between the membrane thickness and the maximum deflection.

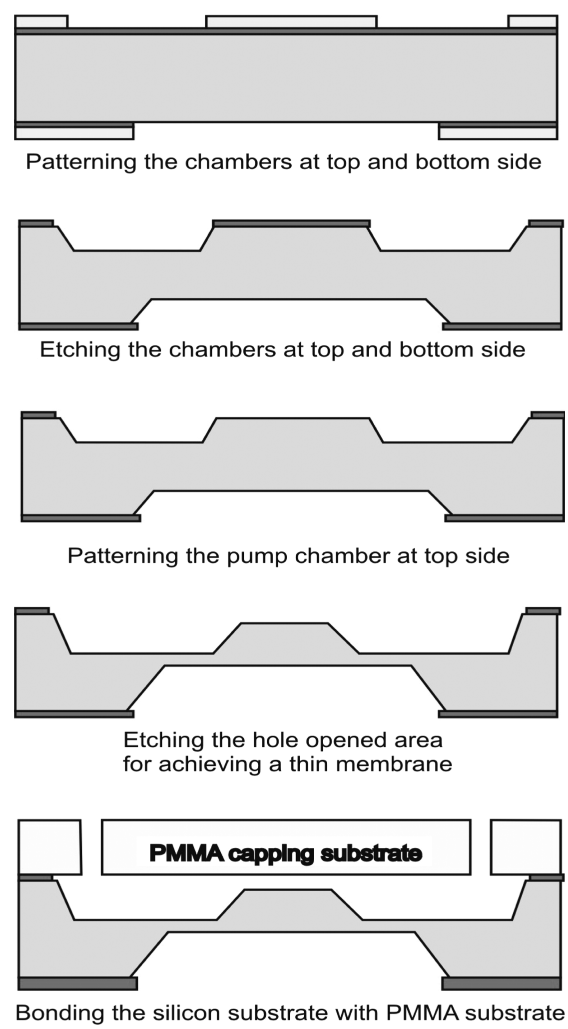

Fig. 4. Schematic process of planar valveless micropump using the double-sided etch-stop technique.

Prior to the etching, the top side of the nitride coated silicon substrate is opened to define the pump chamber area. The area is then etched by using DRIE (deep reactive ion etching). Next, the nitride layer on the back surface is opened to define the piezo-disc chamber. The defined patterns are used as the mask for the silicon etching in KOH solution. The solution is heated in a glass beaker until it reaches the etch temperature at 80°C. Then, the etching process of both sides of the silicon wafer takes place simultaneously. 200 min of etching is required to achieve a 200 μm deep chamber. At this step, 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 areas are etched together for 50 min.

A piezoelectric disc is bonded on to the silicon substrate by sticking it inside the piezo-disc chamber using conductive epoxy material. The top and bottom contact of the piezo-disc are fabricated by evaporating a 200 nm thick aluminum layer. The inlet and outlet channel are produced by drilling the PMMA substrate. In the final steps of the process, the silicon substrate and capping substrate are bonded together using thick AZ 4620 resist to isolate the chamber from the environment.

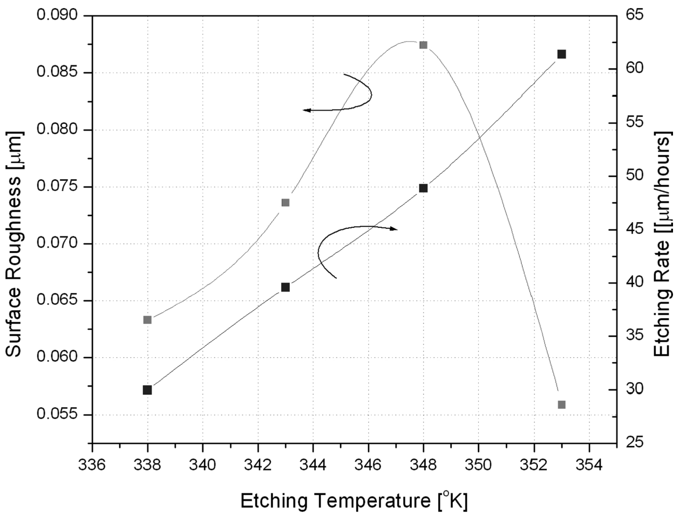

Fig. 5. Surface roughness and etching rate of 35% KOH solution at various temperatures.

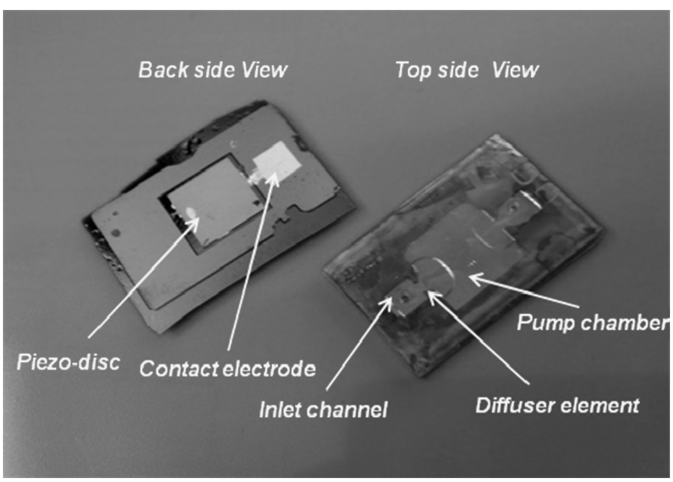

Fig. 6. Photograph of fabricated pump at back side and front side.

Results and Discussion

Some process parameters have been experimented in order to find an appropriate surface quality of the chamber and membrane. For this purpose, a 35% potassium hydroxide (KOH) solution is prepared by mixing a 42.76 g KOH pellets into a 100 mL H_2O. The test samples are then etched at four different solution temperatures of 65°C, 70°C, 75°C, and 80°C with an etching periode of 30 minutes. 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. 5. The results showed that the increase in solution temperature up to 75°C causes an increase of the surface roughness. It is also shown that the etching rate increases with the temperature. From the analysis, it can be shown that the etching process at the solution temperature of 80°C is the optimum etch parameter. Therefore the fabrication of the silicon membrane is carried out at this optimum concentration and temperature.

The fabricated membrane structure from the top and bottom side view is presented in Fig. 6 After etching the silicon substrate using 35% KOH solution, a 200 μm silicon trench is produced properly, a 54.7° angle side slope from the plane is approved, and a smooth and clean surface are observed (Fig. 7a and 7b). The 35% KOH solution at 80°C is chosen due to the controllable etch rate of about 1 μm/min. A completely etched silicon membrane results after etching the silicon for a total of

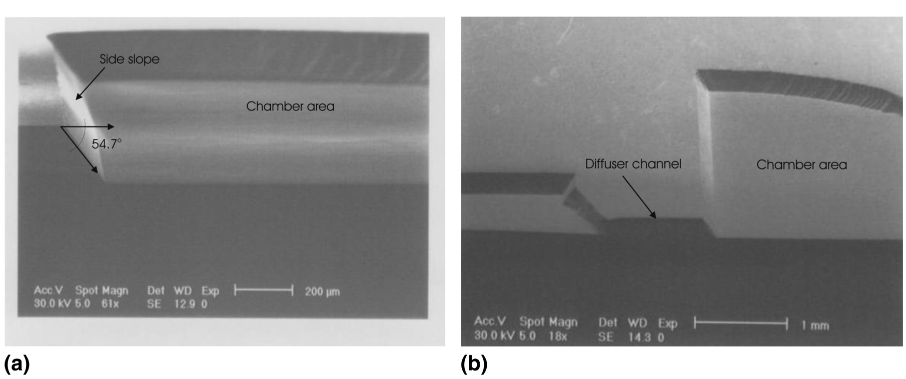

Fig. 7. Surface view of fabricated pump chamber.

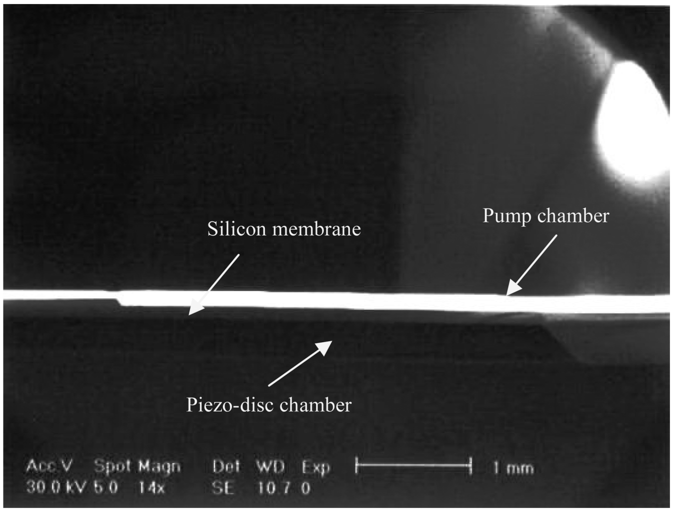

Fig. 8. Cross section view of fabricated membrane after double sided silicon etching.

250 min. The silicon substrate has a thickness of 650 µm. Therefore, etching of 250 µm deep silicon at each side of silicon substrate is enough to achieve a 150 µm thick silicon membrane. As a result, a 50 µm deep diffuser/nozzle, 250 µm deep chambers, and 150 µm thick silicon pump membrane are produced (Fig. 8).

Conclusions

A piezoelectric micropump with planar nozzle/diffuser elements has been fabricated using a simple MEMS process technique. The micropump is designed to provide liquid delivery at a desired steady flow. A double sided etch technique is used to simplify the process and makes the fabrication of the micropump easier and more time-efficient. Due to its miniature size and low flow rate, this pump is capable of providing high accuracy doses as prescribed for each individual usage. The work presented here illustrates the feasibility and merits of utilizing a simple MEMS process technique for fast and reliable fabrication of valveless micropumps.

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