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Piezoeletric Micropump for Drug Delivery System Fabricated Using Two Optical Masks

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Abstract. In this study, a Piezoelectric Actuated Valveless Micropump (PAVM) has been designed and successfully fabricated using MEMS fabrication processes. A PZT: Pb (ZrTi) Ox (lead titanate zirconate) disc is used to actuate a silicon membrane by applying an alternating electrical field across the actuator. The resultant reciprocating movement of the pump membrane is then converted into pumping effect. Preliminary analysis of the fluidic characteristics of this micropump was performed using CoventorWare Simulator with MEMs-FSI (Fluid Structure Interaction) module to understand the working behaviour of the pump system. The pump is fabricated in a simple micromachining process with two optical masks using a double side polished silicon wafer. The tests carried out on the micropump have produced promising results to be used in the drug delivery system.

Introduction

Given the market potential for applications in microfluidics and drug delivery especially, micropumps are of considerable interest to researchers and industrial utilizations. This is made easier with the establishment of microfabrication methods used to manufacture a wide range of miniature pumps [1]. MEMS-based microfluidics drug delivery devices in general include microneedles-based transdermal devices, osmosis-based devices, micropump-based devices and microreservoir-based devices and biodegradable MEMS devices. One recent key application of micropumps in biomedical industry is to provide a means to deliver insulin to many diabetic patients, thus providing an alternative to injections. Such types of micropumps can be programmed to administer insulin at a constant rate throughout the day, thus eliminating any surges or deficits of the drug in the patient's bloodstream [2][3].

Valveless piezoelectric micropumps are in wide practical use due to their ability to conduct particles with the absence of interior moving mechanical parts yield less risk of clogging [4]. They are also responding quickly and have obvious advantages over other kinds of micropumps. Nozzle-diffuser elements, also known as dynamic passive valves are being used in this study. Additional benefits of nozzle-diffuser elements include the ease of manufacture using conventional silicon micromachining techniques, and the much higher flow rates achievable with vibrating membrane pumps employing such valves. The simple structure of the micropump imposes a strong mechanical coupling from the membrane to the pump chamber volume and, finally, to the dynamic valves. Hence, small secondary energy losses only will occur even at higher actuation frequencies. The oscillating membrane is the only compliant element of the whole pump.

The advent of modern photolithographic techniques and bulk micromachining that has allowed the miniaturization and mass production of today's semiconductor integrated circuit has enabled for the creation of micro-mechanical device. The fabrication process involved in this work is very straightforward, demanding only the standard MEMS technologies. The use of silicon has also advantages over metals as pump materials, e.g. in applications with an aggressive medium a silicon/glass pump may be more resistant than a metal pump.

PAVM Design and Analysis

A Piezoelectric Actuated Valveless Micropump (PAVM) is a complex fluid-structure coupled system consisting of a piezoelectric actuator, silicon membrane, pump chamber, working fluid and micro-diffusers. The design of the micropump involves the knowledge of electro mechanics, solid mechanics and fluid mechanics. So far, there is no accurate, flexible and broadly applicable analytical model available for micropump system design and analysis. With certain assumptions, some progresses have been achieved on low-order lumped parameter models which can provide certain insights on key aspects of micropump operation, but it cannot provide an accurate prediction [5].

To accurately predict the working behavior of the micropump, based on the membrane vibration equation and Navier Stokes flow equation, the fluid-structure dynamic coupling effects should be taken into account. Because of the complexity of the micropump, the analytic flow solution is impossible, and the full 3D numerical solution is extremely difficult. To overcome this, it is ideal to carry out 3D-FSI simulations to investigate the micropump in details. FSI is generally relevant when a structure surrounded wholly or partly by a fluid is flexible in response to the motion of the fluid. MemFSI module in CoventorWare's design tool is targeted at the solution of this class of problems. The 3D simulations of the micropump is significant for micropump design, performance analysis and evaluation of other system simulation.

In order to understand the working principle of a typical piezoelectric micropump during which the liquid droplets are ejected out of the nozzle on the basses of deformations of a piezoelectric material under electric filed and interaction of a silicon membrane and a working fluid across the fluid structure interface, a cross-sectional view of the piezoelectric micropump is displayed in Fig. 1.

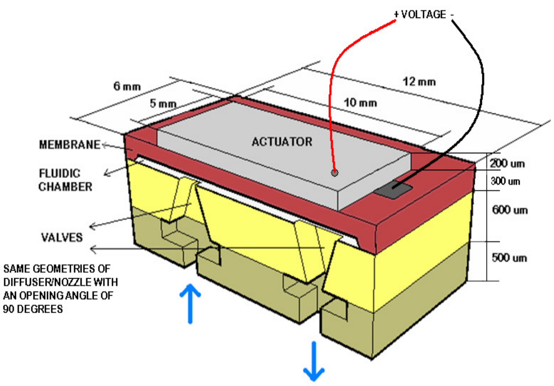

Fig. 1 3D Cross section of the designed PAVM

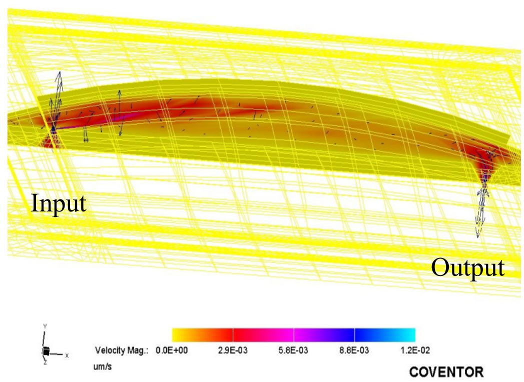

Fig. 2 Velocity vector slice in z-plane.

In this work, a complete 3D simulation for a piezoelectric valveless membrane micropump is carried out using the MemFSI, with the consideration of fluid-structure interaction. The optimized geometrical dimension for the micropump was performed earlier by simulated the micropump design part by part separately i.e. fluid part and 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 silicon membrane. Then the optimized dimensions are applied to the system. Simulation result in Fig.2 shows the micropump in action when being driven with 10 V input voltage. We can clearly observed the fluid flow from the input throughout the output and the velocity vector confirmed the flow type movement is laminar.

Process and Fabrication

In this process, a double side processing of silicon with two optical mask patterns is acquired. Double side anisotropic etching process of first silicon substrate is used for creating the pump membrane and nozzle/diffuser valves. Double side alignment structures are necessary because both the inlet and outlet valves and the pump chamber are etched at the same time from both sides of the wafer. Prior to the etching, both sides of silicon substrate which are coated by nitride layer is defined by etching the nitride layer using DRIE. The defined pattern is used as mask for the KOH etching. A 35% KOH solution is prepared by mixing a 42.76g potassium hydroxide (KOH) pellets into a 100 ml H_2O. The solution is heated in a glass beaker until it reaches the etch temperature at 80^oC. Then, the etching process of both sides of the silicon wafer takes place simultaneously. As predicted, a 275 µm silicon trench is produced properly, a 54.7^o angle side slope from the plane is approved and smooth and clean surface are also observed. The 35% KOH solution at 80^0C is chosen due to the controllable etch-rate of about 1 µm/minute. Therefore, etching of 275 µm deep silicon at each side of silicon substrate is enough to achieve 100 µm of membrane thickness. The similar process sequence is implemented for creating the nozzle/diffuser valves on the second substrate however 650 minutes KOH etching is required to completely etched the silicon for creating the valves. Finally, both substrate is bonded using epoxy glue to isolate the chamber from environment (Fig. 3).

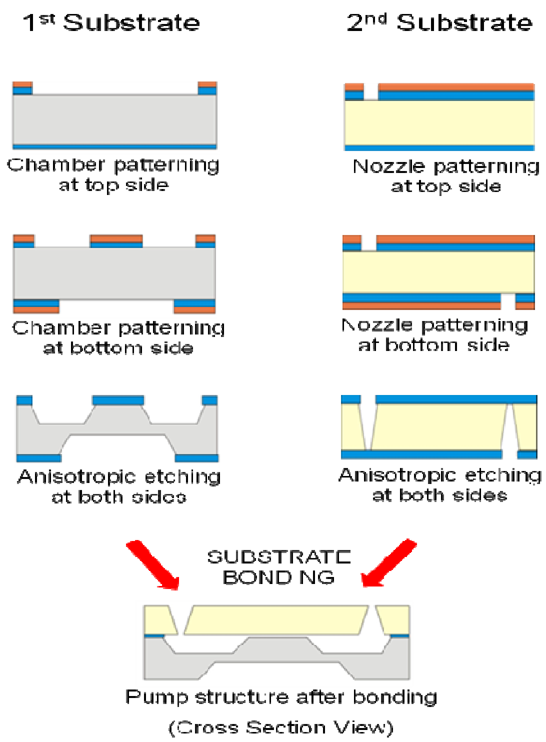

Fig. 3 Schematic process steps for fabricating micropump using bulk micromachining process

The fabricated completely etched valves with a 54.7^o angle side slope from the plane is presented in Fig. 4. The piezoeletric disc is then glued onto the silicon membrane using conductive paste.

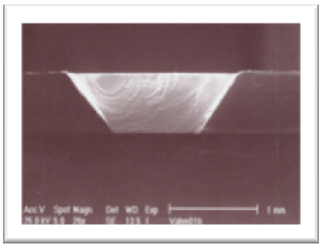

Fig. 4 Cross-section view of the fabricated nozzle/diffuser valve (SEM photo)

Conclusion

A piezoelectric membrane micropump with nozzle/diffuser elements has been designed and fabricated to provide drug delivery at a desired steady flow rate. 3D-FSI simulation and analysis on the micropump design assisted in getting the accurate model for the system. Using only two optical masks to simplify the process makes the fabrication of the micropump becomes easier and time saving. Due to miniature size and minute flow rate, this pump is capable of providing high accuracy doses as prescribed in for each individual patient. The work presented here illustrates the feasibility and merits of utilizing a piezoelectrically driven micropump for drug delivery, in particular for patients affected by diabetes.

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