Electromagnetic Micro-Actuator with Silicon Membrane for Fluids Pump in Drug Delivery System

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***Abstract*—An electromagnetic (EM) micro-actuator with silicon membrane has been fabricated and characterized. The studied silicon based membrane is used as an actuator of a micropump system driven by magnetic force. The actuator consists of two main parts, namely, the electromagnetic part that generates electromagnetic field and the magneto mechanical part that enables the membrane deformation depending on the magnetic force strength on the silicon membrane. A standard Micro Electronic Mechanical System (MEMS) process was implemented to fabricate the actuator with an additional bonding between the actuator membrane and electromagnetic coil. The measurement results show that the 20 µm thin silicone membrane is capable of deformation with a maximum membrane deflection of approximately 4.5 µm which will be useful for a reliable fluids pump in a continuous drug delivery system.**

***Index Terms*—Electromagnetic micro-actuator, silicon membrane, microfluidic pump, drug delivery**

I. Introduction

Silicon has been an important material in the microelectronics industry for decades due to its semiconducting property, high thermal stability, and high mechanical strength, hence making it suitable for a suspended membrane. Silicon material is already available in the market at a relatively cheap price and is also known as common material in IC (integrated circuit), in which its fabrication technology is well established.

On the other hand, a deformable membrane has been an essential element in a fluid pumping system as an actuator that functions to create pressure difference inside the fluidic chamber, therefore enabling the transportation of the fluidic sample from storage to the human body or to a biological analysis system. Some of the potential applications of such an actuator are continuous insulin delivery, the injection of dialysate solution in a portable dialysis machine [1], and for fluid sample injection in lab-on a chip system [1, 2, 3].

A compact and small micro-pump system for biomedical application is necessary to achieve the precise dosage of the sample injection and optimum fluid transport, where a low sample volume with precisely controlled fluid injection flow and low energy consumption are demanded [4]

Therefore, there is a growing demand in the area of the actuator to reduce the actuator dimension and to increase the performance of the injector with precise flow control, while keeping the energy consumption of the system as low as possible. From the point of view of the technological aspect, there is the trend to fabricate the device with a simple process and low fabrication cost, as well as the possibility of integrating the injector devices with other part of the microfluidic systems, which drives the technology to move away from the use of discrete fluid pump system and toward the use micro-scaled fluidic injection system monolithically integrated with other medical devices.

Several types of micro-actuators have been investigated, such as the thermal pneumatic actuator [5], electrostatic actuator [6, 7], and piezo electrically driven actuator [7, 8]. The first two types of actuators are implementing the material that is directly attached to the flexible membrane. The continuous attacking of the physical, such as heat or mechanical, can cause damage and material cracks that reduce the reliability of the actuator membrane. An electrostatically driven micro-actuator requires a high input voltage implementation to enable a sufficient membrane deformation; this is not suitable for a portable system where the low energy consumption is highly considered. A piezo-electrically driven actuator has been the most implemented concept to drive the membrane actuation; however, the use of wire connection between the metal electrode and the

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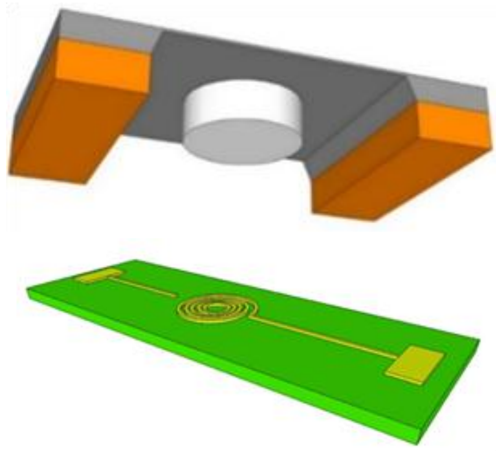
piezo material to the external electrode could reduce the deformation capability of the membrane.

Based on above reasons, the electromagnetically driven actuator seems to be the best alternative micro-actuator for a portable micro-pump system due to its low power, flow control precision, and higher membrane reliability. Furthermore, the silicon is chosen as the membrane since it has a high surface strength and can withstand failure due to the continuous vibration. On the other hand the fabrication of the silicon membrane established since many years ago can simplify the fabrication process. Finally, the silicon monolithic based membrane concept opens up the possibility of integration between the micro-actuator part and the CMOS based control circuitry.

Therefore, in this paper we report the study on electromagnetic actuator with silicon based membrane material and structure as well as appropriate parameters suitable for the actuation purpose of the micro-pump system. The effect of the coil and input power on the actuator performance will be discussed in detail.

II. The Design of EM Micro-Actuator

The initial structure of the electromagnetic micro-actuator consists of the combination between magnetic and mechanical parts, known as the Magneto-mechanic part (Figure 1a). This part includes the thin film deformable membrane, magnetic chamber, and the permanent magnet. The second part of the system is called the electromagnetic part, which includes the current carrying planar micro-coils on glass or PCB substrate lying perpendicular to the permanent magnet (Figure 1b).



(a)

(b)

Figure 1. The schematic of micro-actuator part: the magneto-mechanic part (a) and the electromagnetic part (b).

Fig. 2 shows the schematic view of the electromagnetic micro-actuator. The membrane deformation is produced due to the interaction between the permanent magnet and the electromagnetic field of the coil. Theoretically, when an electrical alternating current flows through the micro-coils, a generated magnetic field Hz will interact with the permanent magnet on the membrane with the magnetic induction of Br and the area size of Am at the vertical distance hm above the coil. This interaction produces magnetic force Fz that periodically pushes and pulls the flexible membrane.

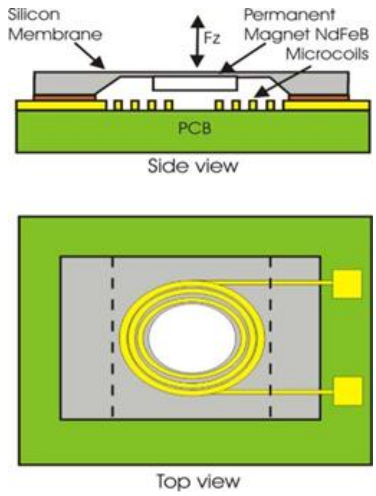


Figure 2. The schematic of the electromagnetic micro-actuator structure

The generated magnetic force F_z can be calculated as follows,

$$F_z = B_r A_m \int_z^{z+h_m} \frac{\partial H_z}{\partial z} dz \qquad (1)$$

The magnetic force causes the thin membrane to vibrate periodically. The membrane deformation W_{max} is dependent on the mechanical property of the membrane, the shape and geometry of the membrane, and the magnetic force F_z acting on to the membrane surface. The deflection height W_{max} for a square type membrane is calculated as follows [5],

$$w_{max} = C \frac{F_z \; lm^2}{(h^2)} \left(\frac{12(1-v^2)}{Eh^2}\right) \qquad (2)$$

Where, C is the constant depending on the shape and geometry, l_m is the membrane dimension, v is the poison's ration, E is the young modulus of the membrane material, and h is the membrane thickness.

III. EM Actuator Fabrication

The micro-actuator parts can be fabricated separately, namely, the fabrication of the electromagnetic part (1) and the fabrication of magneto-mechanic part (2), which is then finally followed with the bonding of both parts using epoxy (3). The detailed fabrication process of the micro-pump system is shown in Figure 3.

Initially, the fabrication of the actuator starts with the creating of the planar Cu micro-coil wire (a). The planar coil is fabricated by etching the electroplated Cu metal sheet on PCB using FeCl3. The coil pattern has three different widths such as 100, 150, and 200 µm with a space between the coil of 100 µm. The coil has 5 turns to form a planar parallel spiral coil.

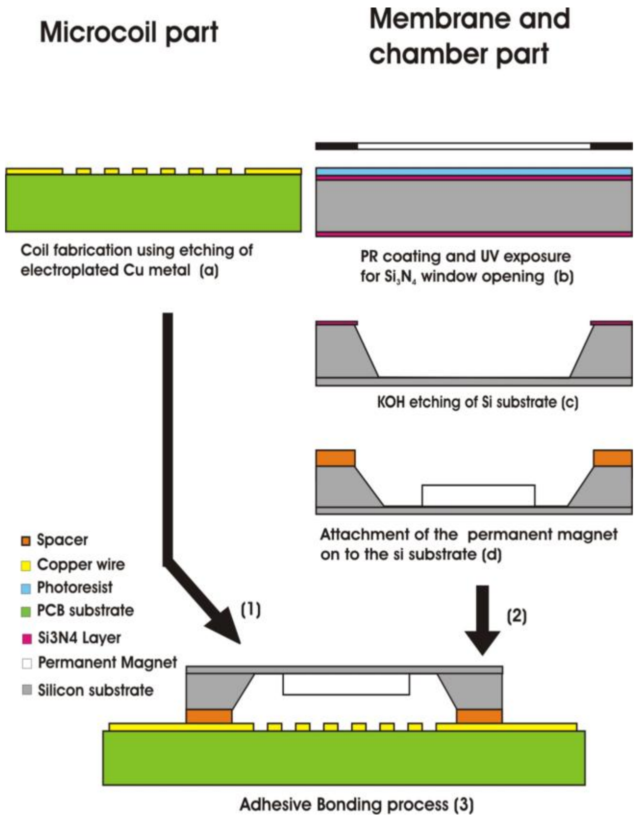


Figure 3. The process flow for the fabrication of electromagnetic actuator

Next is the fabrication of the magneto-mechanical part involving the patterning process of the chamber using standard Photolithography (b), the fabrication of the magnetic chamber and the silicon membrane using anisotropic silicon etching using KOH solution (c), and the attachment of the permanent magnet magnetic NdFeB on to the membrane (d). The process is finally completed with bonding both fabricated structures using epoxy glue (3).

IV. Results and Discussion

As seen in Figure 4, the measurement setup for the characterization of the actuator consists of the power supply, the laser displacement meter to analyse the deformation height of the membrane lying perpendicular to the deforming membrane surface, and the gauss meter to analyse the strength of the magnetic field density produced by the electromagnetic coil, ohm meter.

During measurement process, the sample is put on a vibration free stage. The membrane deformation is driven by an input AC current supplied by a power supply and connected to the planar coil wire. The input current is varied from 200 mA up to 1 A. The Laser Displacement Meter measures the resulting membrane deflection. The value of the Gauss meter is then calculated using Eq. (1) to get the generated magnetic force value.

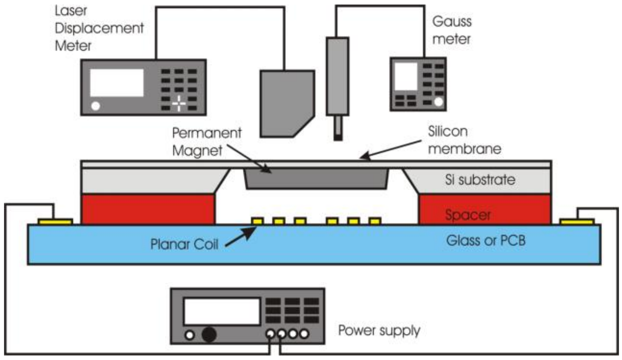


Figure 4. The setup of the measurement system

The measurement result of the magnetic field density generated by the coil is shown in Figure 5. In general, the simulation result is moderately matched with the measurement that validates the results. The comparison between the simulation and measurement results shows that the simulation results reveal a higher value than that from the measurement. This is possibly due to the ideal case considered in the simulation parameter. On the other hand, several lost factors in the measurement process, such as inner resistance on Gauss meter and power supply contributes to the reduction of the measurement precision.

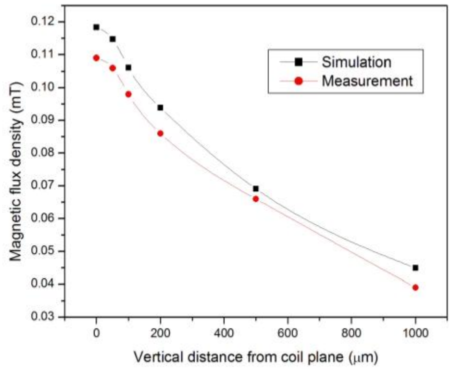


Figure 5. Comparison of the magnetic flux density between the simulation and measurement for an input current of 500 mA.

The characterization of the electrical and mechanical property of the actuator was done to see the effect of the coil parameter and input power on the deformation characteristics of the membrane. It is shown in Figure 6 that the membrane deformation increases with the input current, which correlates with the strength of the generated magnetic force. Furthermore, it can be seen that if we use coil wire with a small current flow area, the resistance of the coil will increase, hence the power consumption will be also higher. On the other hand, the larger cross section area of the coil doesn't improve the generation of the magnetic field, which is probably due to the eddy current effect. It is also shown in Figure 7 that the maximum membrane displacement of approximately 4.6 μm for a power consumption of approximately 0.8 Watt was revealed.

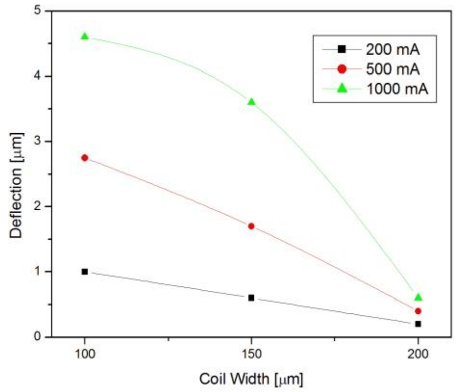


Figure 6. The deflection characteristic of the microactuator at various coil configurations for a membrane thickness of 30 µm

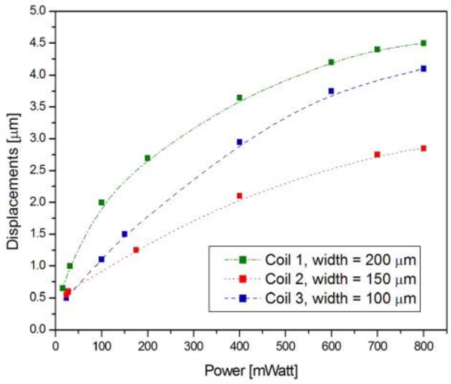


Figure 7. The deflection characteristic of the microactuator at various electrical applied powers for a membrane thickness of 30 µm

V. Conclusions

An EM Actuator with a silicon based membrane was fabricated and characterized. The actuator consists of an electromagnetic coil, silicon membrane, and attached NdFeB permanent magnet. The fabrication of the actuator system was simple and including the fabrication of the membrane, the fabrication of electromagnetic coil, and the bonding process. The functionality of the actuator was tested by applying an AC input current, while the deformation capability of the membrane was measured using laser displacement meter. The measurement result showed that the generated force increases significantly with the applied power on the coil. The analysis of the electro-mechanical characteristics of the actuator shows that the 20 µm silicon membrane was able to deform as high as 4.5 µm, which is significantly reduced with the input current. The maximum deflection height was observed for an 800 mWatt of input power. The result of this observation would give promising for the future development of silicon based integrated electromagnetic micro-pump for continuous insulin drug delivery and lab on chip application.

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