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AN ELECTROMAGNETIC ACTUATOR IN LAB-ON-A-CHIP SYSTEMS

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ABSTRACT

A novel technique for the fabrication of electromagnetic micro actuators was proposed and a prototype was designed and fabricated in this study. The constituent parts of the designed actuator are comprised of the diaphragm, the micro coils, and the magnet. When an electrical current was applied to the micro coils, the magnetic force between the magnet and the coil is produced, causes the diaphragm to deflect and becomes the source of actuation. The fabrication process of the actuator combines Optical Lithography, Electron Beam Evaporation, and Electroplating. The structure of the actuating device uses PDMS as the vibrating diaphragm and electroplated copper as the coils. The diaphragm deflection can be regulated by varying the electrical current passed through the micro coil and hence the actuating effects can be controlled. The experimental results show that the maximum diaphragm deflection within elastic limits is 150 μm at an electrical current of 0.6 A for a micro coil of 100 μm line width. The micro electromagnetic actuator proposed in this study is easily fabricated and is readily integrated with Lab-on-a-Chip systems due to its planar structure.

Keywords: electroplating, magnet, micro coils, micro actuator, PDMS

INTRODUCTION

In the current century both environmental protection and economic development have become two major considerations regarding consumer products. Forms of the products will tend to be light, thin, short and compact, and their functions will be considered about their occupied space, consumed energy, and material reduction. Micro-Electro-Mechanical Systems have been regarded as a major technology and become a proactive research field in the last decade. Micro actuators are machines which need input controlled signals, such as electrical voltage and current. These signals can be converted into the motions of micro-actuators, such as horizontal movement, vertical vibration, and swinging, moreover, their component size should be in the micron-sized level [1]. Static, electromagnetic, and piezoelectric [2-10] actuators are the principal devices in the development of the Micro-Electro-Mechanical Systems. Liu *et al.* [2] fabricated magnetic flaps that were meant to be integrated parts of an active micro electro-mechanical fluid control system. Though a large deflection (~ 100 μm) was achieved, the integration into a micro-fluidic system was not demonstrated in their study. Judy and Muller [3] proposed a magnetically activated device for switching light paths in micro-photonic systems, which was still hard to be integrated into planar biochips with a pumping function. Lagorce *et al.* [4] presented magnetic microactuators based on polymer magnets with good simulated and experimental results. Their cantilever design with small defection (~ 20 µm) was not demonstrated as a pumping element in micro-fluidic systems. A valveless micropump using electromagnetic actuation was successfully presented in Ref [5]. A PDMS (polydimethylsiloxane) diaphragm with a magnet was actuated by an externally electromagnetic actuation. A successful pumping phenomenon was observed with the developed micropump in spite a bulky and external actuation was required.

The current study presents a new micro electromagnetic actuator utilizing a PDMS diaphragm with a tiny magnet attached. The actuator is integrated with micro coils to electromagnetically actuate the diaphragm and results in a large deflection. The electromagnetic micro actuator proposed in this study is easily fabricated and is readily integrated into Lab-on-a-Systems chips due to its planar structure.

2. DESIGN

As shown in Fig.1, the actuator was constructed with the micro coil electroplated onto the glass substrate with a polyimide layer for isolation and the PDMS diaphragm [5, 10] with permanent magnets bonded to the PMMA layer. The copper coil was electroplated onto the glass substrate. The PDMS diaphragm was formed by spin-coating to reduce its thickness. The magnet used in the actuator is a bulky, permanent magnet because its dimensions can be easily chosen and no ex-work is required. The shape of the micro coil was designed as 100 µm line width with 80 µm spacing (Fig. 2). The size of the selected magnet was 1.5*1.5 mm with a magnetization retentive capacity of 2300 Gauss.

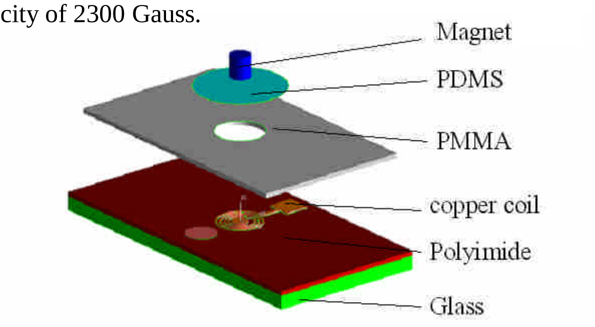


Figure 1 Sketch for the construction of the fabricated electromagnetic actuator.

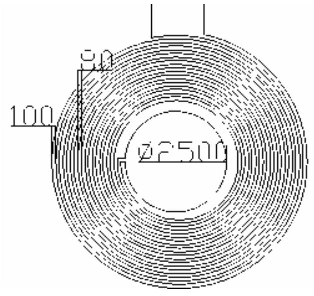


Figure 2 Micro coil design. The width, spacing and thickness of the coil are 100 µm, 80 µm and 20 µm, respectively.

3. FABRICATION

The electromagnetic actuator was fabricated by surface micro-machining technology which includes the standard photo lithography, the vacuum evaporation and the electroplating processes. Micro spiral coils are first fabricated using standard photo lithography and electroplating processes. A simplified fabrication process of the micro coils is shown in Fig 3. The fabricated spiral micro coils were designed as 10 turns and the process started with a glass substrate. The fabrication process for micro coils is described as follows:

(a) Onto the glass substrate, a seed layer consisting of 30 nm chromium and 150 nm copper was deposited using electron-beam evaporation.
(b) A15 µm thick polyimide layer (PW-1000, Toray Industries Inc., Japan) was spread on the seed layer with a via hole to connect the seed layer and the micro coil. Then the substrate was cured in a 350℃ oven to solidify the polyimide layer.
(c) Electroplating 15µm thick of copper in the via hole.
(d) A 25 µm thick photo resist layer (AZ 4620, Clariant Corp., Switzerland) was then spun on the top of the polyimide layer and patterned to form molds of micro coils. A seed layer of 100 nm copper was deposited using electron-beam evaporation.
(e) The copper coils were then electroplated with 20 µm thick. Upon completion of the electroplating, the photo resist mold was removed with acetone.
(f) A15 µm thick polyimide layer served as an insulation layer, was spun on top of the copper coils and cured at 350℃ for 1 hour after removing the photoresist and the seed layer.

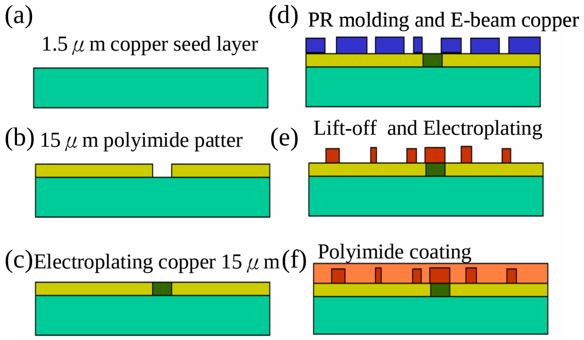


Figure 3 Simplified fabrication process for the micro coils.

The photographs of the fabricated micro coils were shown in Fig. 4.

The materials of fabricated PDMS diaphragms are made of silicon resin and silicone elastomer (18D, Sylgard, Taiwan) by the weights ratio of 10:1. The PDMS material was spun on a glass wafer, on which was spread a layer of photoresist (AZ4620). The photoresist was a "sacrificial layer" and lifted off following the solidified PDMS diaphragm. Basically, the spin rate of coating is reversely proportional to the coated PDMS thickness.

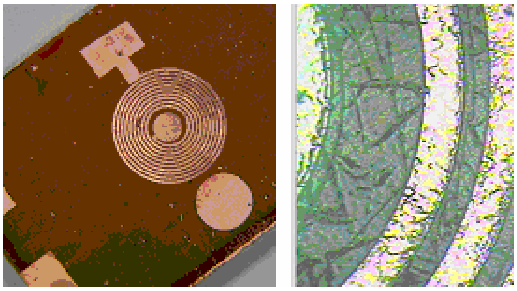


Figure 4 Photographs of the electroplated coil.

The fabrication process of the PDMS diaphragm can be simply described as follows.

(a) Clean the glass substrate using an acetone solution.
(b) A photo resist layer (AZ 4620) was spun on the front side of the substrate as a “sacrificial layer”.
(c) A 100 μm PDMS diaphragm (weights ratio: silicon resin to silicone elastomer is 10:1) was spun on the glass wafer with the pre-spun PR layer. The substrate was then cured in a 100^{o}C oven for 20 minute to solidify the PDMS diaphragm.
(d) The substrate was put into acetone to strip off the PDMS diaphragm.

Fig. 5 represents the photograph of a fabricated PDMS diaphragm with a thickness of 100μm and a photograph of the bonded part of the bulky magnet, the PDMS diaphragm and the PMMA substrate. A hole with a 4 mm diameter was drilled through the PMMA substrate at its center. To complete fabrication of the designed electromagnet actuator, a UV-glue bonding procedure to bond the fabricated parts was necessary. All design parameters of the components of the fabricated actuator are summarized in table 1. A photograph of the fabricated magnetic actuator is represented in Fig. 6.

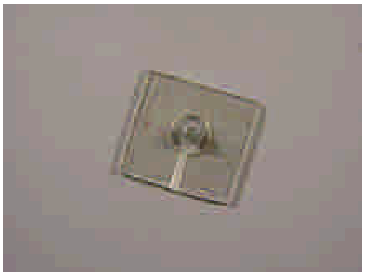
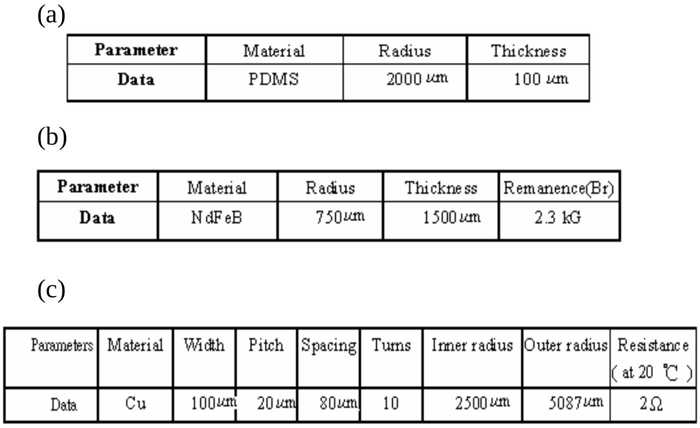


Figure 5 Photograph of the bonded part for PDMS diaphragm, PMMA layer and bulk magnet.



(a)

Parameter	Material	Radius	Thickness
Data	PDMS	2000 ㎛	100 ㎛

(b)

Parameter	Material	Radius	Thickness	Remanence(Br)
Data	NdFeB	750㎛	1500㎛	2.3 kG

(c)

Parameters	Material	Width	Pitch	Spacing	Turns	Inner radius	Outer radius	Resistance (at 20 ℃)
Data	Cu	100㎛	20㎛	80㎛	10	2500㎛	5087㎛	2Ω

Table 1 (a) Parameters of fabricated diaphragm, (b) parameters of bulk magnet and (c) parameters of fabricated micro coil.

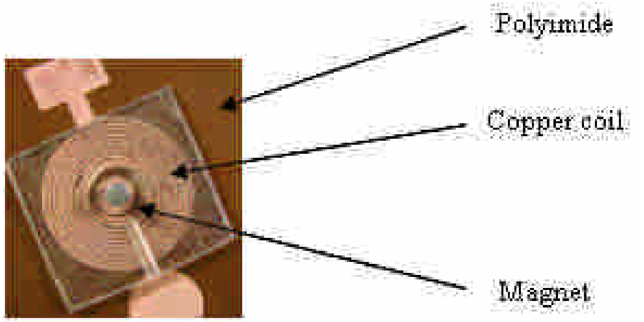


Figure 6 Fabricated electromagnetic actuator. in this research.

4. EXPERIMENTAL RESULTS

To investigate the experimental results, the magnetic field produced by the micro coils is measured using a Tesla meter (model 4048, F. W. Bell, U.S.A.). The variation of the flux density is measured from the coils plane and along the central axis of the coil for an input electrical current of 0.5 A.

Fig. 7 shows the experimental results of the micro coil. It can be found that the maximum magnetic field is measured at a distance of 500μm from the center of the coil with 100 μm. A steeper curve can be observed, which means a greatest flux density can be produced with the design of the coil. Furthermore, the corresponding derivatives of the flux density, as shown in Fig. 8, are shown as the gradient of the magnetic field produced by the coil. It can be seen that the maximum gradient of the magnetic field occurs at a point located 1200μm above the planar coil. Therefore, the magnet should be located at this position to optimize the electromagnetic actuation effect and the greatest gradient of the magnetic field was generated at a distance of 500 μm from the center of the coil.

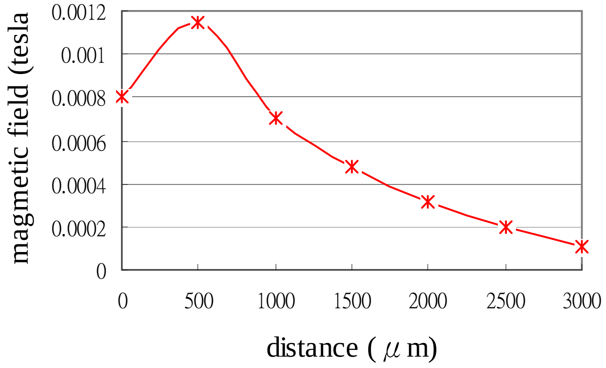


Figure 7 Magnetic field produced by micro coil.

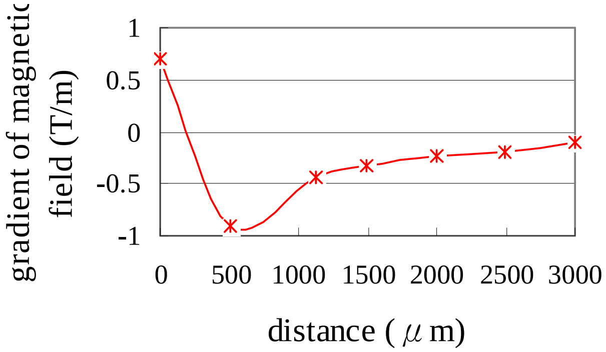


Figure 8 Gradient of the measured magnetic field.

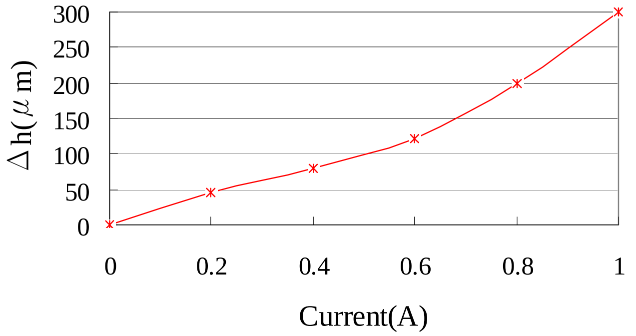


Figure 9 Displacement of the diaphragm actuated by the electromagnetic force.

The displacement of the diaphragm is also measured at its central area (power supply: PR8323, ABM, Taiwan / laser displacementmeter: LC-2400A + 2430, Keyence, Japan), which is occupied by the magnet, where the maximum deflection occurs on the diaphragm. All diaphragm displacements generated by the coil are shown in Fig. 9. It is found that the maximum deflection (300 μm) is measured with an input current of 1.0 A.

5. CONCLUSIONS

The designed magnetic actuator using deflected PDMS diaphragm actuated by electromagnetic force was successfully fabricated in the study. The experimental results show that the fabricated actuator exhibited excellent actuation response with large diaphragm deflections, short response times, high field energy density, and low power consumption. The characteristics of the fabricated actuator make this device useful as an important part of micro pumps and other actuation applications. The results of this study provide a valuable contribution to the ongoing development of Lab-on-a Chip systems due to its planar structure.

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