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Electromagnetic Squeezing Microactuators Using Laterally-Driven Flexible Copper Strips

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Abstract

We present the design, fabrication and testing of an electromagnetic squeezing microactuator array, whose flexible strips generate lateral squeezing and swelling motions for microfluid transportation. A set of prototypes having the flexible strips of different sizes is fabricated by the copper electroplating process using thick photo resist micromold. In the experimental study, we have measured the static and dynamic responses of the electromagnetic squeezing microactuators in the vacuum, air and water environments. The strips, having the lengths of 1mm, 1.2mm and 1.4 mm, generate the static lateral deflections of 10 μm , 18 μm and 19 μm in water for the current supply of 1A with the magnetic field of 0.4G, respectively. The strips show the frequency and damping ratio in the ranges of 23.5~37kHz and 0.11~0.17 in vacuum. The electromagnetic squeezing microactuator shows the dynamic frequency in the rage of 16~35.5kHz with the damping ratio of 0.08~0.15 in water, generating the water transport rate of 20pl/cycle.

INTRODUCTION

Recently, there has been a growing interest in the microfluid transport devices for applications to microinjectors, micropumps and biochemical microsystems. Power devices for the microfluid transport include electrostatic, piezoelectric, thermal, and electromagnetic actuators [1-5]. Among them, the electrostatic actuators [1] are attractive due to the simple structures, but generating small forces using relatively high voltages. The piezoelectric actuators [2] generate large driving forces at higher speed, but generating the actuation amplitude limited to few micrometers. The thermal actuators [3] need higher power, having limited life-time due to thermal stresses. For low-power, large-amplitude and small-size actuators for microfluid transport, we consider electromagnetic actuators [4-5].

In this paper, we present the design, fabrication and testing of an electromagnetic squeezing microactuator (Fig.1) that utilizes the laterally-driven squeezing motion of flexible copper strips for microfluid transport. Conventional electromagnetic microactuators [4-5] utilize the out-of-plane motion of the microfabricated coils on the diaphragms in the magnetic fields. In this paper, however, we propose a new electromagnetic microactuator structure, whose electroplated copper strips generate the lateral squeezing pumping motion using the vertical component of the magnetic field formed by an underlying permanent magnet.

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WORKING PRINCIPLE

Figure 2 shows a schematic view of the squeezing microactuator, composed of an electroplated flexible copper microstrip pairs between the silicon substrate and the glass cap. Figure 3 shows the working principle of the squeezing microactuators using the magnetic field normal to the substrate. When the electrical current is supplied to the copper strips shown in Fig. 3(a), Lorentz force is generated on the copper strips in the squeezing direction of the fluid contained between the microstrip pairs. At the swell mode (Fig. 3(b)), the electrical current is supplied in the opposite direction.

Thus, the alternative directions of the Lorenz force on the microstrip pairs generate in the squeezing and swelling of the fluid. During the cyclic motion, net flow is rectified in one direction due to the diffuser placed at the entrance and exit of the microfluid flow.

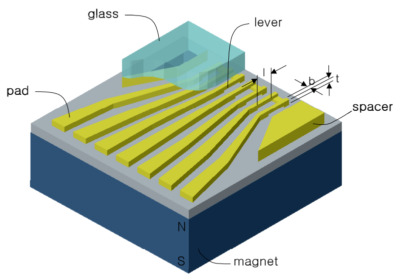


Figure 1. Perspective view of the electromagnetic squeezing microactuator array.

DESIGN AND FABRICATION

In order to characterize the performance of the electromagnetic microactuators, we have designed a set of eight different prototypes (Table 1), having strip pairs in different width, length and thickness. The prototype devices are fabricated by a copper electroplating process using the micromold (Fig.4) and aluminum sacrificial layers. Figure 4 shows the cross section of the 45µm-thick photo resist (AZ9262) mold for 30µm-thick electroplated copper structures.

Figure 5 illustrates the fabrication process of the microactuators. First, we pattern the thermally grown silicon dioxide layer (Fig.5(a)) on the bare silicon wafer, thus drawing the markers for the strip deflection measurement. We deposit the 0.5 µm-thick sputtered aluminum layer (Fig.5(b)) as the sacrificial layer of the microstrips, followed by the deposition of Cr/Cu seed layers (Fig. 5(c)) for copper plating process (Fig.5(c)). The 45µm-thick photo resist lithography process is followed by the 30µm-thick copper electroplating of the microstrip pairs (Fig.5(e)). After removal of the aluminum sacrificial layer (Fig.5(f)), we assemble the devices between the upper glass cap and the lower permanent magnet (Fig.5(g)).

Figure 6 shows the top view and front view of the fabricated electromagnetic squeezing microactuators. As shown in Fig.6(b), the 2µm-thick upper gap between the copper strips and glass surface is formed by the adhesive layer between the device and the glass cap. The permanent magnet for the magnetic field strength of 0.4G is used.

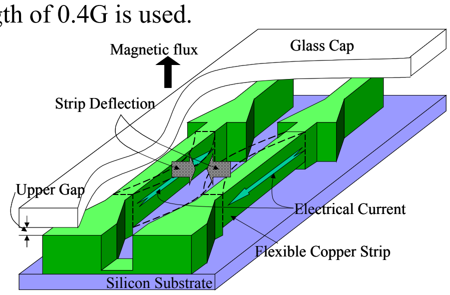


Figure 2. Schematic view of the electromagnetic squeezing microactuators.

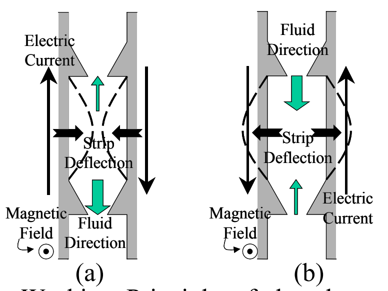


Figure 3. Working Principle of the electromagnetic squeezing microactuators with fluid diffusers: (a) squeeze mode; (b) swell mode.

Table 1. Microactuator prototypes having differentsizes of flexible strip pair.

Prototype No.	Width	Length	Thickness
P1	4.0 µm	1.0 mm	30 µm
P2	6.3 µm		
P3	7.0 µm		
P4	9.1 µm		
P5	5.1 µm	1.2 mm	
P6	9.1 µm		
P7	9.1 µm		
P8	6.0 µm	1.4 mm	

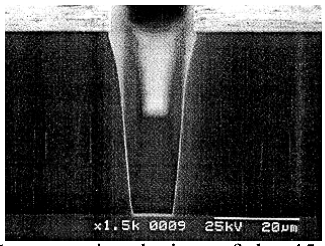


Figure 4. Cross-sectional view of the 45µm-thick PR (AZ9262) mold.

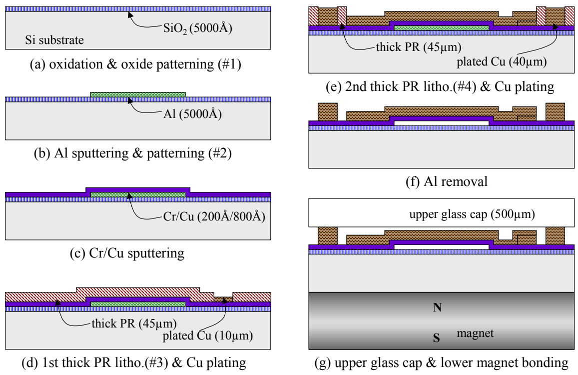


Figure 5. Fabrication process for the electromagnetic squeezing microactuators.

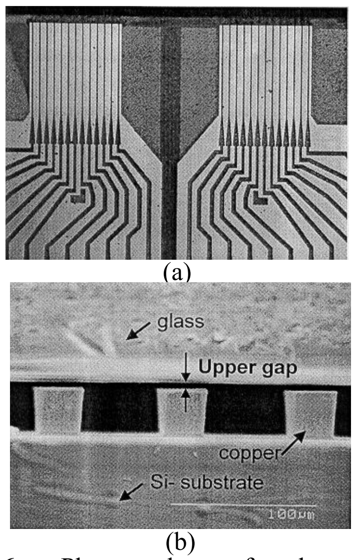


Figure 6. Photographs of the fabricated microactuators: (a) Top view; (b) Front view.

RESULTS AND DISCUSSION

We have measured the mechanical properties of the electroplated copper layer using the Blister test method [6]. Young's modulus and residual stress of the electroplated copper have been measured as 60.38 GPa and 58.65Mpa, respectively.

From the fabricated prototypes, we have measured the static deflections (Fig.7) of the electromagnetically actuated copper strips in water using the permanent magnet of 0.4G. The measured static deflection of the strips agrees well with the theoretical values estimated from the Lorentz force and elementary beam bending theory, while showing deviation for the case of the longest strips (1.4 mm-long strips in Fig. 7).

In the dynamic test, we have measured the frequency response function (FRF) of the microactuators in the vacuum (Fig. 8), air (Fig. 9) and water (Fig. 10) environments, respectively. In the vacuum of 0.05 Torr, the strip actuation shows under-damped motion characteristics for the current supply of 12mA, resulting in the measured natural frequency and damping ratio are in the ranges of 23.5~37.0 kHz and 0.11~0.17, respectively.

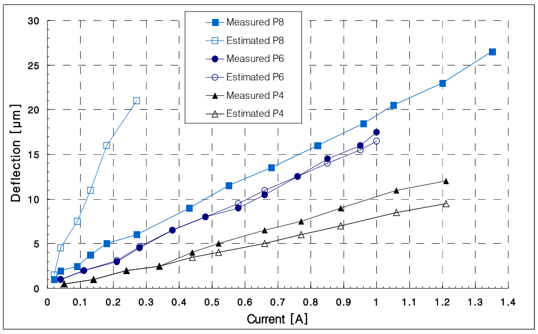


Figure 7. Measured and estimated static response of the electromagnetic squeezing microactuators in water for varying current input: Prototypes P4, P6 and P8 in Table 1.

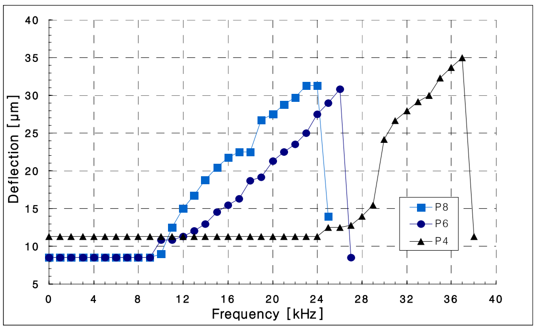
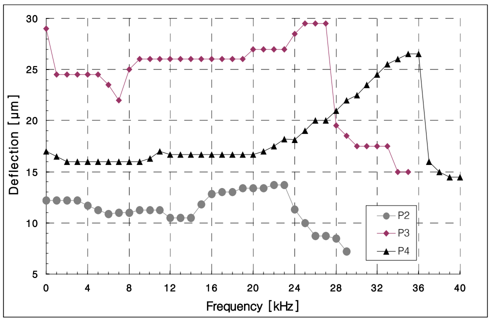
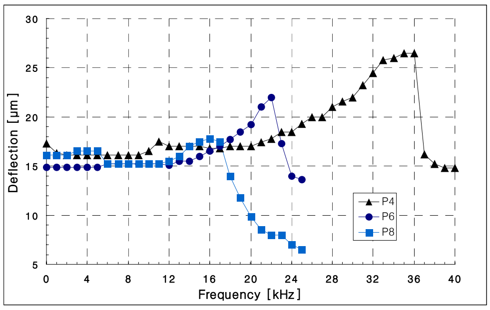


Figure 8. Measured dynamic response of the electromagnetic squeezing microactuators in vacuum for the current input of 12mA: Varying strip length (Prototypes P4, P6 and P8 in Table 1).

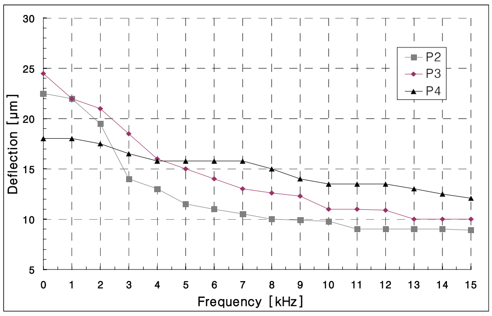


(a)

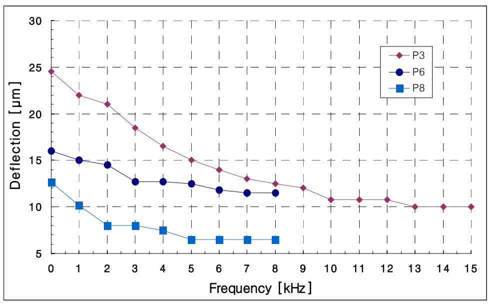


(b)

Figure 9. Measured dynamic response of the electromagnetic squeezing microactuators in air for the current input of 300mA: (a) Varying strip width (Protopypes P2, P3 and P4 in Table 1); (b) Varying strip length (Protopypes P4, P6 and P8 in Table 1).



(a)



(b)

Figure 10. Measured dynamic response of the electromagnetic squeezing microactuators in water for the current input of 500mA: (a) Varying strip width (Protopypes P2, P3 and P4 in Table 1); (b) Varying strip length (Protopypes P3, P6 and P8 in Table 1).

In the air, the microactuators also show under-damped characteristics. The natural frequency and damping ratio of the strip actuation are measured in the ranges of 16.0~35.5 kHz and 0.08~0.15, respectively. In the water (Fig. 9), the microactuators show over-damped characteristics. In the frequency range of 10.0~15.0 kHz, we find that the deflection amplitude is saturated in the range of 10~15μm. We also measure that the net water flow rate of the electromagnetic squeezing microactuators is at 20pl/cycle.

CONCLUSIONS

In this paper, we presented the design, fabrication and testing of the electromagnetically driven flexible strip microactuators, where the squeeze and swell motions of the flexible copper strip generate the microfluid transport rectified by microdiffusers. We designed and fabricated eight different microactuator prototypes having different copper strip sizes. We measured the static response of the prototypes in water and their dynamic response in vacuum, air and water. We found that the microactuators generate the maximum static displacement of 27 μm, proportional to the applied electrical current input. The microactuators generated under-damped dynamic behaviors in the vacuum and air environments, while showing over-damped dynamic behaviors in water. The electromagnetic squeezing microactuators achieved the net flow rate of 20pl/cycle for water. Consequently, we verified that the present electromagnetic squeezing microactuator using the electroplated flexible copper strip pairs has a potential for applications to microfluid transport.

ACKNOWLEDGMENTS

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REFERENCES

[1] S. Kamisuki, T. Hagata, C. Tezuka, Y. Nose, M. Fujii, and M. Atobe, "A Low Power, Small, Electrostatically-driven Commercial Inkjet Head," *Proc. MicroElectroMechanical Systems '98 (MEMS'98)*, Heidelberg, Germany, 1998, pp.63-68.

[2] J. D. Beasley, "Model for Fluid Ejection and Refill in an Impulse Drive Jet," *Photographic Science Engineering*, Vol. 21 (1977) pp.78-82.

[3] A. Asai, T. Hara and I. Endo, "One-Dimensional Model of Bubble Growth and Liquid Flow in Bubble Jet Printers," *Japanese Journal of Applied Physics*, Vol. 26, No. 10 (1987) pp. 1794-1801.

[4] J.-C. Ryu, T.G. Kang and Y.-H. Cho, "A New Transverse Electromagnetic Microactuator using the Radial Magnetic Field Guided by Symmetric Twin Magnets," *Proc. Symposium on Micromechanical Systems*, *Inter. Mechanical Engineering Congress and Exposition (IMECE '99),* Nashville, Tennessee, U.S.A., 1999, pp.105-109.

[5] J. Behrens, A. Meckes and W. Benecke, "Micropump and Valves with Electromagnetic Actuation," *Proc. Micro System Technologies 96*, Potsdam, Germany, 1996, pp.820-822.

[6] J. Y. Pan, P. Lin, F. Maseeh, and S. D. Senturia, "Verification of FEM Analysis of Load Deflection Methods for Measuring Mechanical Properties of Thin Films," *Proc. IEEE Solid-State Sensors and Actuators Workshop*, Hilton Head Island, South Carolina, U.S.A., 1990, pp.70-73.