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Initial Assessment of the Function Experiment of Electromagnetism Driven Micropump

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Micropump plays very important role in fundamental biology, clinical medicine, biochemistry and interfacial physical chemistry as a kind of BioMEMS device. A new type of electromagnetic micropump, that can supply micro liquid flowwith high pumping rates and lower power consumption, has urgently been demanded. In this paper, a new prototype model ofmicropump, that consists of six parts— in/out liquid tube, diffuse/ nozzle, membrane, chamber, electromagnetism coil and permanent magnet— using electromagnetism as the servo actuator is proposed. Where, the diffuse/nozzle acts as one-way valve, the pump chambers are made of Polycarbonate, the membrane is made of Polythylene terephthalate. The overall size of this micropump prototype is 11mm in diameter and 4 mm in height. A maximum pumping rate of 0.21mL/min at the frequency of 5Hz and voltage of 4V is demonstrated, which is one of the lowest power consumption reported in the literature before. Variance analysis experimentshows thatThe influence of frequencyof power is the biggest one, and thicknessof membrane is bigger than voltage of power. Simplified peripheral power supply circuit and control method of micropump is performed. When the supply power is 5V, the pumping rate of one and two power is almost no difference.

Key words: Microfluidics,Micropump, Membrane, Biomedical Applications.

Micro[1] fluidic controlling system based on silicon micro fabrication is an important branch of Micro Electro Mechanical Systems (MEMS). In recent years, microfluidics has become a hot research field because it shown its enormous potential in many areas of research, such as fundamental biology, biochemistry, clinical medicine and interfacial physical chemistry

Shahidian *et al*., 2009; Cui *et al*., 2007; Cui *et al*., 2008; Pan *et al*., 2011; Micropump, as an important executive device of MEMS, plays a very important role in micro systems. With the micropump becoming smaller and smaller, the fabrication of the moving parts becomes more and more difficult. Various physical principles, including electrostatic(Xie*et al*., 2004), electromagnetic(Pan *et al*., 2005), piezoelectric and pneumatic(Huang *et al*., 2008; Huang *et al*., 2009; Yang *et al*., 2009; Chia *et al*., 2010; Guo *et al*., 2004) and Shape Memory Alloy (SMA) pump, etc(Kan *et al*., 2005; Qian *et al*., 2009; Pan *et al*., 2005; Cui *et al*., 2005), have been employed to power peristaltic motion bydifferent groups. Among those, Piezoelectric and SMA drives require high voltage, whereas electrostatic actuation requires the creation of small gaps that complicates the fabrication process. Electromagnetic drive can provide large forces over extended displacements. However, microcoils and ferromagnetic materials always need to be integrated. Currently, micropumps are divided into either mechanical or non-mechanical, depending on how fluidic motion is converted from the external energy source (Amirouche *et al*., 2009).

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In this paper, Authors report on the design, fabrication, and test of a simple low-cost micropump with electromagnetic actuation and a preliminary analysis of the electromagnetic pump which shows the characteristic membrane deflection and fluid flow of pumping.

MATERIALS AND METHODS

Magnetic energy micropumps use the interaction of the magnetic field in the electromagnetic field principle. Figure 1.shows a perspective view of the electromagnetic micropump. The overall size of thismicropump prototype is 11mm in diameter and 4 mm in height. The micropump consists of six parts: in/out liquid tube, diffuse/nozzle, membrane, chamber, electromagnetism coil and permanent magnet, while the diffuse/nozzle acts as one-way valve, and the pump chambers are made of Polycarbonate(PC), and the membrane is made of Polythylene terephthalate (PET). The top layer encapsulates a small permanent magnetic rod in the small chamber. All the material for the making of pump can be found easily and inexpensively.

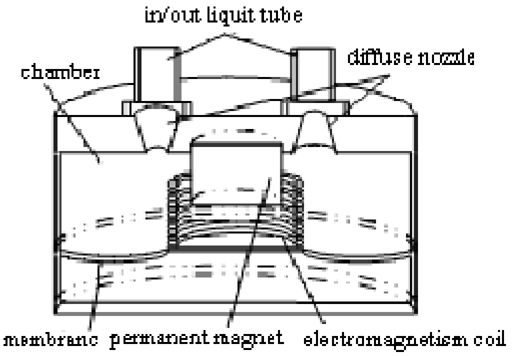

Fig. 1. A perspective view of the electromagnetic micropump

At first, the molds of each layer is fabricated respectively, where the top layer for the microfluidic channels(diffuse/nozzle) connecting to the inlet and outlet, and the middle layer for the actuation membrane an electromagnetic coil loaded on a thin actuation membrane, and the last layer for the base of the micropump. The design presented in this paper, the chambers on the membrane, where one small magnetic rod is loaded in the top layer, which is 1mm in depth, and the micropump chamber construct was machined using materials of Polycarbonate.

The tapered holes which are the diffusion tube and a nozzle (angle 12 °) at both sides of the top layer are opened. The pump body is made into a hollow drum shape with the inner radius of 5.0mm, the outer radius 5.5mm and a height of 2.0mm. An inlet / outlet pipe is installed in the upper portion of the micro-pump specifically in order to access liquid duct conveniently and to protect the micro-pump diffuser tube and the nozzle, whose role is controlling the flow in experiment. The one-way flow of liquid got because the diffusion tube conduct more fluid than the nozzle, as well as in the process that fluid kinetic energy (velocity) is converted to potential energy (pressure) in the pump cavity during a periodic variation of the micro-pump chamber pressure, and the efficiency of the diffuser pipe direction is greater than the nozzle direction. The disc-shaped driving thin film, whose radius is 5.5mm, and a thickness of three sizes are 6ìm, 7ìm, 10ìm, is made of PET material. The electromagnetic coil, with double-layer tightly wound, no skeleton solenoid structure, 60 turns and the inner radius of 2.1mm, resistance 8Ù, adhesively affixed to the drive film. PET film, drove by the interaction of a small permanent magnet (cylindrical shape ö4 × 1.5mm) fixed at the top of the chamber, with magnetic field strength of 0.3 Tesla, and the magnetic field generated by energized coils, promotes the motion of the liquid of the pump chamber. The peripheral circuit of the micropump consists of dual output DC power supply, control circuit and relays, wherein the square wave pulse control signal controls the relay on\ off.Figure 2 is the picture of the micro-pump.

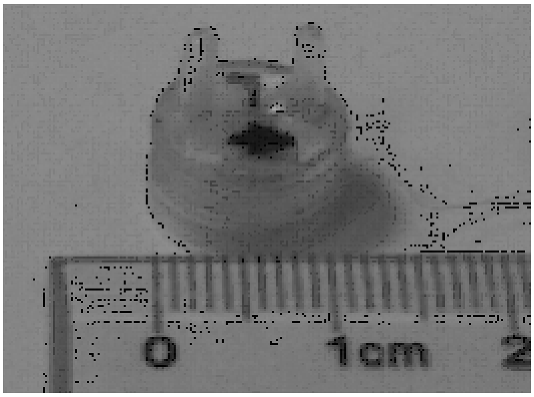

Fig. 2.A photograph of the electromagnetic micropump

In order to know the relationships between the flow rate and operating voltage, working frequencies, thickness of the driving thin film, the pump capability tests using distilled water are performed.

The pump is primed with water before performing the measurements. The priming process must be carefully operated since any air bubble gets into the pump will induce surface tension effects and significantly compromise the pump performance.

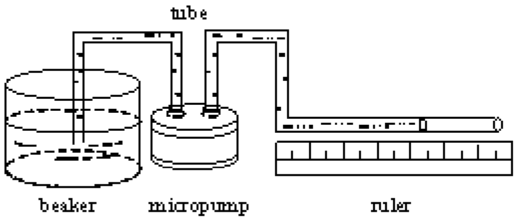

Fig. 3. The test and measurement setup

Level measuring method is used in the experiment to measure the pumping capacity of the micro-pump (flow rate), as shown in Figure 3, Pumping rate measurements are made at pump level . The length of water in the tube is recorded by the ruler when the test started and end. According to the length of water, the amount of water is measured by using a 1mL syringe. The Voltage and current measurements are also taken during 3 minute time period. In order to get the best pumping ability in the experiment conditions, the experiments using orthogonal experimental design method are carried out.

RESULTS AND DISCUSSION

The orthogonal experiments

Three factors, that there are no interaction between factors (film thickness, voltage, frequency), and the three levels are determined finally as the experimental conditions of the micropump, taking into account early exploratory trial and mostly use within the micro-device, normally a low-voltage DC power supply. On the basis of three factors analysis, the orthogonal experiment is: the voltage at the level of 3, 4 and 5V, the frequency at the level of 20Hz,10Hzand 2Hz, the thickness of membrane at the level of 6ìm.,7ìm.and 10ìm.

Table 1. The analyze of orthogonal experiments he result of orthogonal experiments

No. of experiment	Avoltage	blank	Bfrequency	Cthickness	flowml/min
1	1 (3V)	1	1 (20Hz)	1 (6ìm)	0.129
2	1 (3V)	2	2 (10Hz)	2 (7ìm)	0.132
3	1 (3V)	3	3 (2Hz)	3 (10ìm)	0.272
4	2 (4V)	1	2 (10Hz)	3 (10ìm)	0.435
5	2 (4V)	2	3 (2Hz)	1 (6ìm)	0.363
6	2 (4V)	3	1 (20Hz)	2 (7ìm)	0.008
7	3 (5V)	1	3 (2Hz)	2 (7ìm)	0.201
8	3 (5V)	2	1 (20Hz)	3 (10ìm)	0.112
9	3 (5V)	3	2 (10Hz)	1 (6ìm)	0.465
K1	0.533	0.764	0.249	0.957	
K2	0.806	0.607	1.031	0.341	
K3	0.777	0.746	0.837	0.819	
k1	0.178	0.255	0.083	0.319	
k2	0.269	0.202	0.344	0.114	
k3	0.259	0.249	0.279	0.273	
R	0.274	0.157	0.782	0.616	
major → minor			BCA		
optimum relation			$B_2C_1A_2$		

Taking into account the experimental sequence may be influence the test, the test sequence number is extracted at random then, and the test conditions are strictly controlled. The experimental data is the arithmetic average of three measurements.

From Table 1, the optimal operation variables are described through orthogonal experiment, while frequency 10Hz, the thickness of membrane 6ìm, voltage 4V. In order to get the optimum frequency, additional experiment is carried out. Figure 4 shows the pumping rate vs. control frequency at voltage of 4V and film thickness of 6ìm.

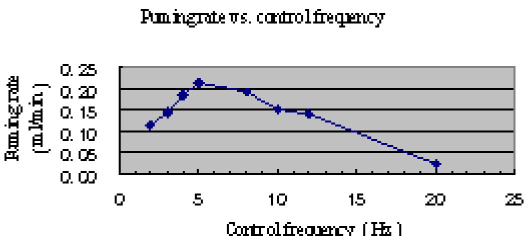

Fig. 4. Pumping rate vs. control frequency

As can be seen, the frequency is the most important factor of the experiment.At lower

Table 2. The variance analysis of result

No.	A	blank	B	C	Results1	Results2	Results3	$\sum_{i=1}^{3} x$	$\sum_{i=1}^{3} x^2$
1	1	1	1	1	0.041	0.041	0.040	0.122	0.005
2	1	2	2	2	0.042	0.042	0.041	0.124	0.005
3	1	3	3	3	0.077	0.086	0.094	0.257	0.022
4	2	1	2	3	0.137	0.136	0.139	0.411	0.056
5	2	2	3	1	0.113	0.115	0.116	0.344	0.039
6	2	3	1	2	0.003	0.003	0.003	0.008	0.000
7	3	1	3	2	0.060	0.064	0.067	0.190	0.012
8	3	2	1	3	0.035	0.040	0.031	0.106	0.004
9	3	3	2	1	0.139	0.146	0.154	0.439	0.064
K1	0.503		0.235	0.904				Σ=	Σ=
K2	0.762		0.975	0.322				2.001	0.208
K3	0.735		0.791	0.774					
R	0.259		0.739	0.582					
K12	0.253		0.055	0.818					
K22	0.581		0.950	0.104					
K23	0.540		0.625	0.599					
$\frac{\sum k_i^2}{9}$	0.153		0.005	0.181					
Q	0.033		0.169	0.021					

Table 3. The analysis of variance

Resource of the variance	Sum of variance	freedom degree	variance	F valve	F critical value	significance
A level	0.005	2	0.002	26	$F_{0.05}(2,20)$	**
B level	0.033	2	0.017	194	=3.49	**
C level	0.021	2	0.010	122	$á_{0.01}(2,20)$	**
Error valve	0.002	20	0.000		=5.85	
Sum	0.06					

In above experiment, the number of measurements n=3×9=27, F valve and the analysis of variance as table 3.

frequencies from 2 to 5Hz, the flow rate follows an approximately linear relationship to the control frequency. However, at higher frequencies from 5 to 20Hz this relationship caps and eventually drops. This happens when the driving frequency approaches and exceeds the mechanical oscillation frequency of the structure, *i.e.*, membrane itself

The whole power consumption is approximately 1.5W. On the other hand, the micropump is suitable for portable battery powered applications because it takes the advantage of low operating voltage (< 5V).

In order to verify the above result, the variance analysis experiment is also performed. The total deviation of the test data, including the influence of various factors, can be presented by variance sum which is the basis for analysis of variance(Table 2).

In above experiment, the number of measurements n=3×9=27, F valve and the analysis of variance as table 3.

As can be seen, the result is influenced by the level of A B and C. The influence of B is the biggest one, and C is bigger than A. From table 3, the optimum relation is B2C1A2 which is same as table 1.

The micropump's performance of one vs. two power supply

In order to apply the micropump to micro-device (such as gastrointestinal micro-electronic capsule), the overall size of the micropump is shrunk. Simplify peripheral power supply circuit and control method of micropump is performed, so the micro-pump pumping preformance of one vs two power supply is compared. Randomly, 10Hz operating frequency and 7ìm thickness membrane are selected. The average value of three times measurement results as shown in Figure 5.

From figure 5, the pumping rate difference of one and two powers supply is gradually decreases with the increase of the supply voltage. When the supply power is 3V, the pumping rate of one power is 67% of two powers. As for 4V, the pumping rate 76% of two powers. As for 5V, nearly 99% of two powers, so that the pumping rate of one and two power is basically no difference.

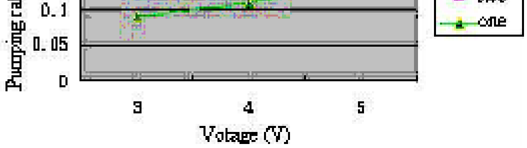

Fig. 5. The pumping rate of one vs. two power supply at 10Hz

CONCLUSION

In this paper, a low-cost micropump driven by electromagnetic has been presented and characterized. The pump is fabricated by PC and PET. Actuation is achieved using one internal magnet and an electromagnetic coil loaded on a thin actuation membrane. The maximum pumping rate was found to be 0.21mL/min, while the power consumption is 1.5W at this pumping rate, which is one of the lowest power consumption reported in the literature before(Pan *et al.*, 2005; Huang *et al.*, 2008; Yang *et al.*, 2009). In order to shrink the overall size of the micropump, simplify peripheral power supply circuit and control method of micropump is performed, When the supply power is 5V, the pumping rate of one and two power is almost no difference. Since a preliminary analysis of the peristaltic pump is performed, the characteristic membrane deflection and fluid flow of pumping are obtained. The next step is to improve and optimize the design, according to the theoretical and experiment analysis, to achieve a higher back pressure and flow rate.

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