Advanced Materials Research
ISSN: 1662-8985, Vol. 422, pp 397-400
doi:10.4028/www.scientific.net/AMR.422.397
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Online: 2011-12-06

Low Cost Diffuser Based Micropump Using Pinch Actuation

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Keywords: electromagnetic micropump, pinch actuation, diffuser based micropump

Abstract. Planar pinch micropump with the integration of two diffuser valve elements has been reported. The fabrication of the micropump is carried out by utilizing simple hot embossing technique for microdiffuser imprinting and spin coating for membrane construction. Parameter of diffuser design is optimized *via* finite element analysis (FEA). The experiment result shows that the pump works well at low frequency of 29 Hz.

Introduction

The maturity development of micro-total analysis system (μTAS) also called "lab on a chip" or microfluidic have initiated micropump research in precision fluid dosing and transportation. Various type of miniature pumps have been developed which are normally classified according to either mechanical or non-mechanical mechanism. The majority of the micropump in the literature falls within mechanical category where the pressure difference created by the membrane displacement drew the fluid in the micropump

A number of actuation principles and operations such as piezoelectric [1-2], shape memory alloy (SMA) [3], thermopneumatic [4] and electromagnetic [5-6] have been utilized in membrane oscillation. Nonetheless, in the viewpoint of portability and low construction cost, electromagnetic actuation shows relatively high potential in creating large membrane deflection under low operating voltage. To ensure the unidirectional fluid flow, integration of diffuser microvalve within pump chamber is essential. Diffuser element, which based on geometry area manipulation principle, requires optimization of parameter design to achieve best directing function.

In this paper, diffuser based electromagnetic pinch planar micropump was fabricated with rapid hot embossing replication technique. Finite element analysis (FEA) was carried out to investigate the fluid dynamic within diffuser element. Parameter tuning in term of pressure loss coefficient and diffuser efficiency with the function of diffuser opening angle was also performed. The characteristic of the micropump reported with flow rate of 2.5 ml/min and back pressure of 15 mmH_2O.

Design and Working Principle

Basic operation of the micropump pinch mechanism is illustrated in Fig. 1.

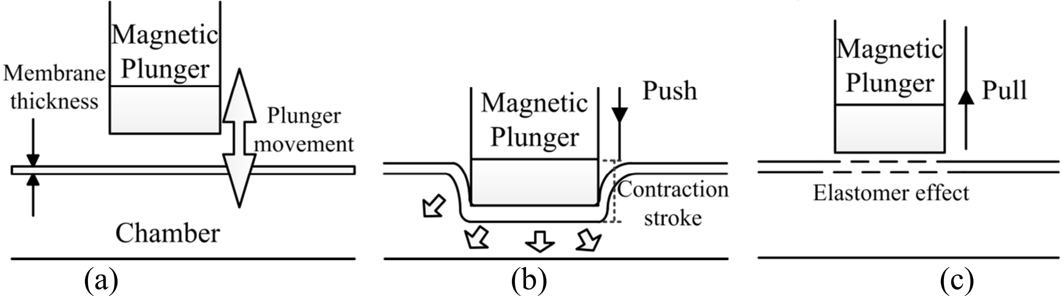


Fig. 1 (a) Schematic of micropump pinch operation. (b) Pinch operation during plunger push state. (c) Membrane restore due to its elastomer effect.

The schematic diagram shows the de-energized magnetic plunger (Fig. 1(a)) located perpendicularly to the elastomer. During push operation, magnetic plunger presses the poly (dimethylsiloxane) (PDMS) membrane introducing contraction stroke to squeeze the fluid out (shown in Fig. 1(b)). With the supply of alternate electrical signal, the induced electromagnetic plunger retracts upward. The membrane immediately returns to its original position due to viscoelasticity properties (refer Fig. 1(c)). Two gradually expand fluidic channels (diffusers) are integrated within pump chamber. They manipulate internal energy where kinetic energy (flow velocity) is transformed into potential energy (flow pressure), resulting to different flow rate in two directions under same applied pressure. The dynamic flow behaviour is highly depended on diffuser geometry configuration, where small changes of cross section design will lead to huge changes in micropump performance.

To achieve high possible fluid directing capability of microdiffuser, two major design key merits should be considered thoroughly: pressure loss coefficient and valve efficiency. In internal flow system, pressure loss coefficient, ξ is depicted as:

$$\xi = \frac{2\Delta P}{\rho \mu^{-2}} \tag{1}$$

Where ρ is fluid density, μ is mean flow velocity in narrow part and ΔP is pressure drop across gradually expanding channel [7].
The valve efficiency,η is taken the ratio between nozzle pressure loss coefficients, ξ_n and diffuser pressure loss coefficient, $\xi_{d.}$

$$\eta = \frac{\xi_n}{\xi_d} \tag{2}$$

To have fluid flow in diffuser direction, the valve efficiency must be greater than one. In other words, the pressure loss coefficient must be lower in diffuser direction compare with nozzle direction. The higher the η, the higher the diffuser fluid directing capability.

Finite Element Analysis (FEA)

2D FEA simulation was carried out with COMSOL Multiphysics to investigate the flow behaviour at divergence channel. Lower pressure coefficient is determined with the variation of half opening angle under constant channel length and Reynold number.

Pressure loss coefficient calculated *via* Eq. 1 is shown in Fig. 2. Two major parameters in calculation are gained from the simulation result: changes in pressure difference and mean velocity.

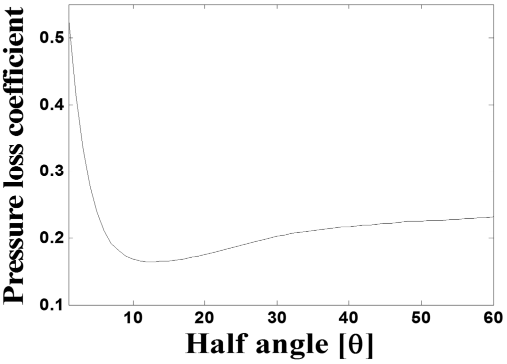


Fig. 2 Pressure loss coefficients with half angle variation

From the graph, best geometry design lies within 5 ˚< θ < 15 ˚, where lowest pressure loss is observed. According to White [8], fluid flow losses mainly result from non-ideal pressure recovery and wall friction. For θ < 5 ˚, pressure loss is high due to channel friction loss. In the case of θ > 15 ˚, poor pressure recovery that caused by flow separation contributes to the increase of pressure loss. This small diffuser angle obtained is similar with Gibson's research [9] where minimum loss occur at diffuser angle of $2\theta \approx 11^{\circ}$ and associate with loss coefficient, $K \approx 0.175$. Half opening angle of 6 ° was chosen for the diffuser design, where pressure loss coefficient, K calculated as 0.21 and result to efficiency, $\eta = 2.89$ which indicate the fluid directing properties can be achieved with the proposed geometry design.

Microfabrication

To realize micropump structure, two fabrication techniques were deployed: hot embossing for microdiffuser imprint and spin coating for membrane fabrication. A thermoplastic PMMA sheet and mold template was placed between two aluminums block which function as isothermal heating and cooling plate. The configuration was then transfer to 110 °C preheated oven for 5 minutes. The configuration was then removed from oven and cooled at room temperature. To avoid cracks on the PMMA due to internal stress, the imprinted PMMA should be removed immediately. PDMS (Sylgard 184, Dow Corning Corp, Midland, Michigan, USA) with mixing ratio of 10: 1, resin: hardener was mixed and degassed before spin coated at speed 1000 rpm for 30 seconds. The PDMS sheet was then adhered onto the pump structure with UV adhesive glue.

Result and characterization

The complete micropump is shown in Fig. 3 which consists of a stand-alone diffuser micropump and actuator.

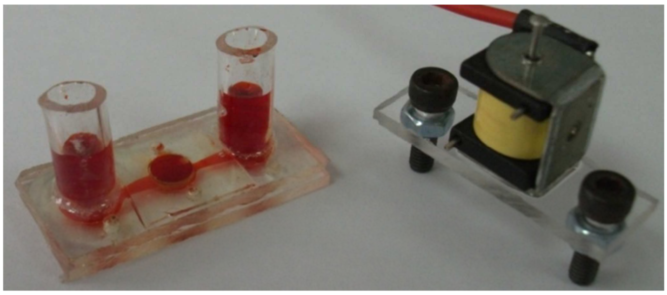
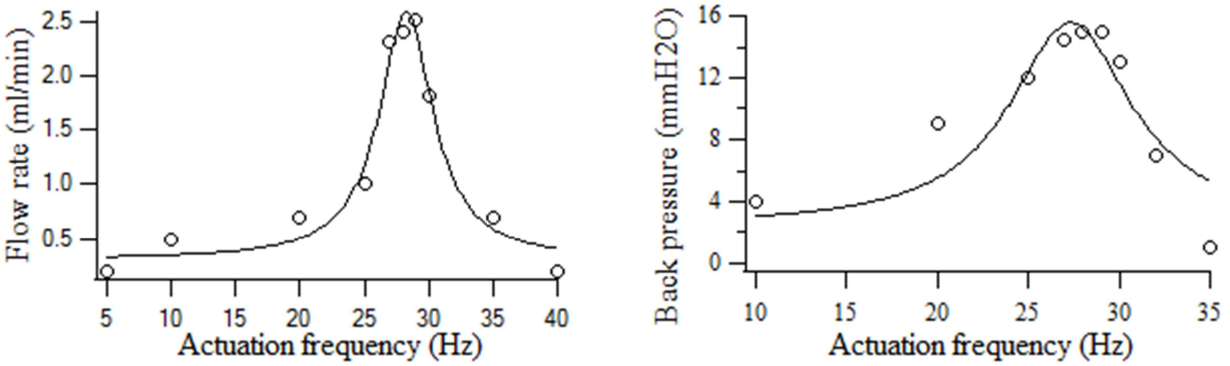


Fig. 3 Pinch actuation micropump

To characterize the pump behaviour, flow rate and back pressure were evaluated under pinch actuation. Acrylic tubing is connected to the outlet fitting and water level was set to the same height as the inlet fitting. By measuring the change of water level over a time interval (30 seconds), the back pressure can be measured. Maximum flow rate can be determined at zero back pressure condition. The flow rate characteristic is described in Fig. 4(a) and back pressure characteristic in Fig. 4 (b).



(a) (b)

Fig. 4 (a) Flow rate of pinch micropump (b) Pinch actuation back pressure characteristic

From the graph (Fig. 4(a)), it is seen that the flow rate increases until optimum frequency, 29 Hz. Beyond 29 Hz, the flow rate decreases due to smaller pinch action of plunger towards membrane. Almost no pumping effect was observed when the frequency more than 40 Hz. To evaluate the capability to withstand external pressure exert, back pressure of the micropump is characterized (see Fig. 4(b)). The back pressure characteristic poses same graph behaviour as flow rate where optimum back pressure occur at 29 Hz. Further increase of actuation frequency will not contribute to the increase of back pressure force.

Conclusion

In this paper, pinch operation micropump was demonstrated where the design parameters and fabrication technique are described. To enhance the pump performance, parameter of the diffuser design is investigated *via* FEA. Simple hot embossing technique was utilized for micropump construction with PMMA material which appear to be good rapid prototype technique to be further integrated in disposable biomedical application due to its low cost, bio-compatibly and chemical inert properties.

Acknowledgements

The authors would like to acknowledge the Ministry of Higher Education of Malaysia for sponsoring this research study through the MyPhD scholarship. This research study is also funded by the Malaysia Fundamental Research Grant Scheme, Vote 78623 and UTM - Universiti Grant (GUP) Vote Q.J130000.7123.01J43.

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