Proceedings of the ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and 8th International Conference on Nanochannels, Microchannels, and Minichannels
FEDSM-ICNMM2010
August 1-5, 2010, Montreal, Canada

FEDSM-ICNMM2010-30949

THE EFFECT OF MATERIAL PROPERTIES ON THE EFFICIENCY OF VALVE-LESS RECTIFICATION MICROPUMPS

Ahmed Fadl [a,b,c], Stefanie Demming[c], Zongqin Zhang[a], Björn Hoxhold[c] , Stephanus Büttgenbach[c], Mannfred Krafczyk[b], and Donna M. L. Meyer[a]

[a] *Department of Mechanical, Industrial and Systems Engineering, University of Rhode Island, Kingston, RI, USA*

[b] *Institute of Computational Modeling in Civil Engineering Technische Universität Braunschweig, Braunschweig, Germany*

[c] *Institute of Microtechnology, Technische Universität Braunschweig, Braunschweig, Germany*

ABSTRACT

High efficiency valve-less rectification micropumps are essential in developing effective microfluidic systems. Many parameters have been reported in the literature to have an effect on the efficiency of valve-less rectification micropumps. These parameters are related to the dynamics of fluid flow (such as Reynolds number), rectifying geometries, or actuators (such as actuator frequency). In this work, we studied the effect of the material properties on the efficiency of valve-less rectification micropumps. Two valve-less rectification micropumps based on the same rectifying geometry, bifurcation, are fabricated using two different materials, Polydimethylsiloxane (PDMS) and SU-8 photoresist. The pumps are tested and results are compared. Experimental results suggest that the material properties have an apparent effect on the pumping performance of valve less rectification micropumps. The results are presented in terms of flow rates and maximum back pressures.

INTRODUCTION

Valve-less rectification micropumps are mechanical micropumps that have no-moving-parts and deliver favorable flow rates compared to other mechanical and non-mechanical micropumps. In addition to delivering favorable flow rates, valve-less rectification micropumps are reliable, cost effective, self-primed, and compatible with many materials and fluids, fabricate with ease, and pump particles-laden fluids as well as life cells [1-4]. Many valve-less rectification micropumps have been reported in the literature with different rectifying geometries such as nozzle/diffuser, Tesla, and bifurcation [6-8]. Studying the factors that affect the micropumps' efficiency is the main theme in the reported works. Reynolds number, microfluidic diodicity, frequency, voltage, signal type, and geometrical parameters for both rectifying geometries and PZT actuators are among the factors that have been investigated [9-14]. However, the effect of the material property on the efficiency of valve-less rectification micropumps has not been reported in the literature. In this study, we have fabricated two valve-less rectification micropumps based on bifurcation geometry using two different materials. The first micropump is fabricated using elastic material, Polydimethylsiloxane (PDMS), and the second is fabricated using inelastic material, SU-8 photoresist. Both micropumps are tested at the same operational conditions.

DESIGN

Figure 1 shows the design and dimensions of the valve-less rectification micropump based on bifurcation geometry. The bifurcation geometry is used to rectify the oscillatory flows generated by a PZT actuator. Despite its role as a rectifier, the nature configuration of the bifurcation has offered the potential for mixing and pumping at the same time. The current design has on generation which will allow mixing of two fluids. The bifurcation has one primary channel (200µm) and two secondary channels (100 µm), and the angle between the secondary channels is 90º degrees. The pump chamber is 10 mm diameter and surrounded with alignment structures to easily align the PZT actuator.

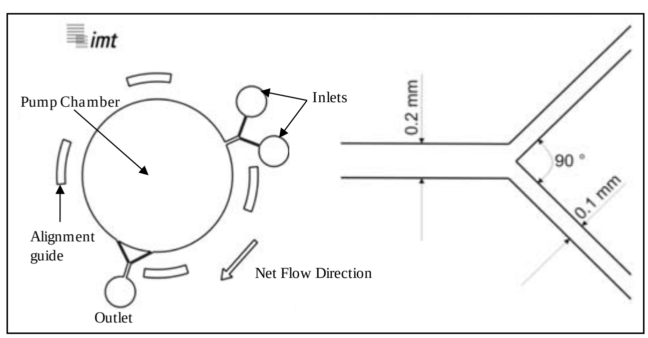

Figure 1: The design of valve-less rectification micropump based on bifurcation geometry

FABRICATION

Softlithography is employed to fabricate the first micropump while opticallithography for the second one. One photo mask is written for each micropump . The first mask is used to meet the requirements for PDMS Replica molding (REM) method, where the micrpump structure is transparent and the rest is opaque. One the other side, the photo mask that is used with SU-8 micropump is written in the opposite way, the micropump structure is opaque and the rest is transparent. Writing the first mask is the first step to fabricate the SU-8 master which used later in the REM. A sods-lime glass was employed to seal the PDMS channels using plasma oxidization.

The second photo mask is used to directly fabricate the micropump in SU-8, then, the SU-8 channels are sealed with soda-lime glass by using silicone glue dispensed from a micro dispenser. The thickness of the SU-8 that is used for both micropumps is 230 µm. Figure 2 shows cross sections of both micropumps after fabrication.

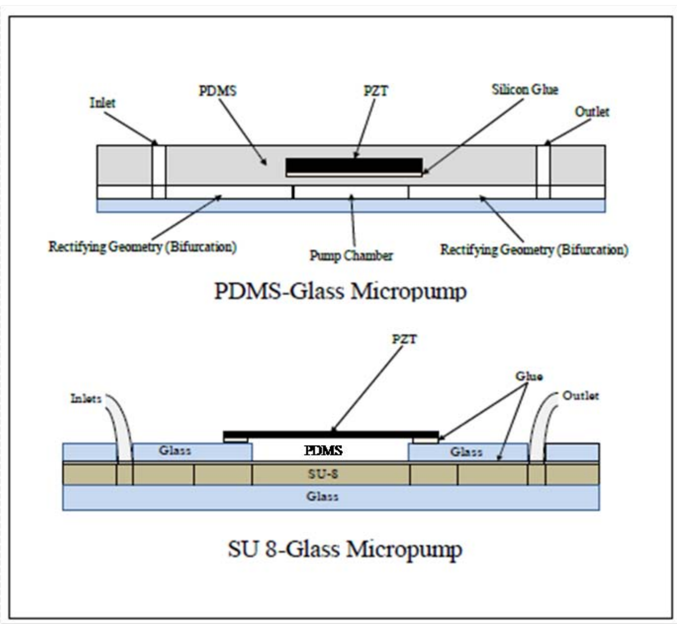

Figure 2: Cross sectional views for both micropumps: PDMS based micropump and SU-8 based micropump

EXPRIMENTAL APPARATUS

Figure 3 shows the experimental apparatus which is used in the present work. The experimental apparatus consists of an amplifier (E-508.00 HVPZT, PI Physik Instrumente, Karlsruhe, Germany), a frequency generator (Agilent 33220A, Agilent Technologies Deutschland GmbH, Böblingen, Germany), an oscilloscope (Tektronix, Japan), a digital microscopic camera (dnt Gmbh, Dietzenbach, Germany), and a laptop. A square signal and 220 V with a zero offset were used to control the PZT. The micropump was investigated against a range of actuator frequencies between 0 and 300 Hz with 50 Hz increments. Ethanol is used as a working fluid for all experiments. Flow rate measurements were conducted based on the bubble tracking method [15]. A length scale (ruler) was attached to the experimental stand for back pressure measurements (ethanol column height). The digital microscopic camera was fixed under the micropump chamber to monitor the flow in real time during the experiments. The real-time monitoring of the flow behavior during the experiments provided assistance to analyze the experimental data. A blue dye (Pelikan, Hannover, Germany) was used in the experiments to better visualize the flow behavior and clearly track the position of the air bubble inside the inlet/outlet tubes. The frequency and the voltage were monitored during the experiments by using an oscilloscope.

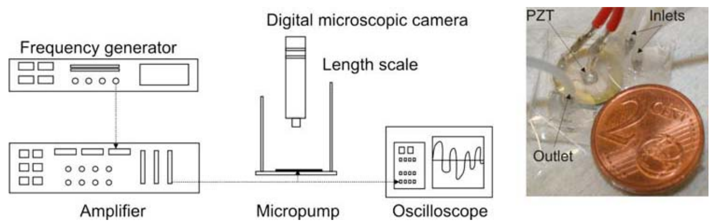

Figure 3: The experimental apparatus; the vale-less rectification micropump based on rectification geometry.

RESULTS AND DISCUSSIONS

Figure 4 shows the results in terms of flow rates vs. actuator frequency. It can be shown that the valve-less rectification micropump based on SU-8 has over come the one which based on PDMS. In both cases, the flow rate has increased monotonically with the frequency and reached the maximum at 300 Hz. In the case of the PDMS micropump, the maximum flow rate is 116 µl/min. On the other hand, the maximum flow rate in the case of the SU-8 micropump is 472 µl/min. Additionally, the maximum back pressure (at zero flow rate) for the PDMS micropump and SU-8 micropump are 2.86 kPa and 4.3 kPa, respectively. The results suggest that fabricating the micropump using rigid material such as SU-8 has a positive impact on the micropump efficiency in comparison with elastic material such as PDMS. The results may be explained in two ways. First, during the sinusdoidal motion of the PZT a distortion may occurred to the rectifying geometry due to the elasticity of the PDMS, as a result, the microfluidic diodicity of the rectifying geometries has been negatively affected and the efficiency decreased. Second, the PDMS may have absorbed part of the sinusoidal motion of the

PDMS due to its elasticity, and as a result, the PDMS has worked as a shock absorber for PZT actuator. This may led to the decrease of the absolute PZT displacement and, consequently, the micropump efficiency.

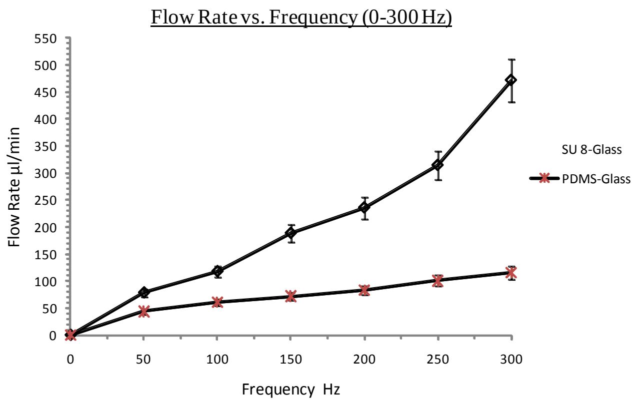

Figure 4: Flow rate vs. Frequency for valve-less rectification micropumps based on bifurcation geometry and fabricated from two different materials

CONCLUSION

Two valve-less rectification micropumps based on bifurcation geometry are fabricated from two different materials. The first is fabricated from PDMS and the second from SU-8. Both are tested at a low frequency range (0-300 Hz). The results suggest that fabricating these types of micropumps from rigid materials has a positive impact on their performance. The micropump that is fabricated from SU-8 has delivered four times the flow rate that is delivered by PDMS-fabricated micropump at 300 Hz. Moreover, the SU-8 micropump has higher maximum back pressure than the PDMS micropump. Despite the simplicity and cost effectiveness of using PDMS, employing PDMS may result in less efficient valve-less rectification micropump due to its elastic property.

ACKNOWLEDGMENTS

The research described in this paper was supported by the National Science Foundation (NSF), grant no.: OISE-0530203

REFERENCES

[1] Nguyen N, Huang X, Chuan TK (2002) MEMS-micropumps: a review. J Fluid Eng 124:384–392

[2] Laser DJ, Santiago JG (2004) A review of micropumps. J Micromech Microeng 14:35–64

[3] Iverson B, Garimella S (2008) Recent advances in microscale pumping technologies: a review and evaluation. Microfluid Nanofluid 5:145–174

[4] Amirouche F, Zhou Y, Johnson T (2009) Current micropump technologies and their biomedical applications. Microsyst Technol 15:647–666

[5] Stemme E, Stemme G (1993) A valve-less diffuser/nozzle based fluid pump. Sens Actuators A 39:159–167

[6] Forster FK, Bardell L, Afromowitz MA, Sharma NR, Blanchard A (1995) Design, fabrication and testing of fixed-valve micropumps. Proc ASME Fluids Eng Div ASME 234:39–44

[7] Fadl A, Demming S, Zhang Z, Buettgenbach S, Krafczyk M, Meyer D (2009) A Multifunction and Bidirectional Valve-less Rectification Micropump Based on Bifurcation Geometry. Microfluid Nanofluid DOI: 10.1007/s10404-009-0544-0

[8] Fadl A, Zhang Z, Geller S, Tolke J, Krafczyk M, Meyer D (2009) Numerical Investigation of the Geometrical Effect on Microfluidic Diodicity using Lattice Boltzmann Method. Microsyst Technol 19(5):1379-1387

[9] Olsson A, Stemme G, Stemme E (1997) Simulation studies of diffuser and nozzle elements for valve-less micropumps. Transducers 97, June 16–19, Chicago, USA

[10] Olsson A, Stemme G, Stemme E (2000) Numerical and experimental studies of flat-walled diffuser elements for valve-less micropumps. Sens Actuators 84:165–17

[11] Sun CL, Huang K (2006) Numerical characterization of the flow rectification of dynamic microdiffusers. J Micromech Microeng 16:1331–1339

[12] Cui Q, Liu C, Zha XF (2008) Simulation and optimization of a piezoelectric micropump for medical applications. Int J Manuf Technol 36:516–524

[12] Yang K, Chen I, Shew B, Wang C (2004) Investigation of the flow characteristics within a micronozzle/diffuser. J Micromech Microeng 14:26–31

[13] Wang Y, Hsu J, Kuo P, Lee Y (2009) Loss characterization and flow rectification property of diffuser valves for micropumps application. Int J Heat Mass Transf 52:328–336

[14] Rosa S, Pinho FT (2006) Pressure drop coefficient of laminar Newtonian flow in axisymmetric diffusers. Int J Heat Fluid Flow 27:319–328

[15] Yoon J, Choi J, Lee H, Kim M (2007) A valveless micropump for bidirectional applications. Sensors Actuators A 135:833–838