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-ICNMM2010-30950

A MULTIFUNCTIONAL MICROFLUIDIC DEVICE BASED ON BIFURCATION GEOMETRY

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

Developing multifunctional devices are essential to realize more efficient Microsystems. With miniaturization processes taking place in many different applications, the rooms for single function microfluidic devices are limited. In this study, we introduce a multifunctional micro fluidic device based on bifurcation geometry which is capable of performing pumping and mixing at the same time. Optical lithography is used to fabricate the designed microfluidic device. The microfluidic device is tested at low actuator frequencies, and ethanol is employed as a working fluid. The operational principles are based on rectifying the oscillatory flows by using bifurcation structures for flow rectification. The results prove the feasibility of the novel design, and results are presented in terms of flow rates and maximum back pressures.

INTRODUCTION

Micropumps are important parts in many Microsystems such as Micro Total Analysis System (µTAS) and Lab-On-a-Chip (LOC). Despite the varieties in micropumps, only few micropumps deliver efficient flow rates, work with wide range of working fluids, and fabricate with ease [1-4]. Valve-less rectification micropumps are displacement mechanical micropumps that have many advantages over other types of micropumps such as no moving parts, easy to fabricate, reliable, having the ability to pump particle-laden fluids and live cells, being compatible with a wide range of microchannel materials and working fluids, and delivering a favorable flow rate and back pressure [5-7]. However, many microsytems require mixing of different fluids prior to the pumping step. As a result, several Microsystems have both micromixers and micropumps installed on-a-chip [8]. Despite the advantages of valve-less rectification micropumps, integrating the mixing function into those micropumps has not been yet achieved. The conventional valve-less rectification micropumps are based on nozzle/diffuser and Tesla geometries, and they are mono-functional, therefore, they are not capable of performing mixing and pumping at the same time [9,10]. Moreover, these geometries are not typically implemented in microarrays and have to be fabricated solely for flow rectification. The Bifurcation geometry has high microfluidic diodicity and was used in to develop a multifunctional microfluidic device [11, 12]. However, the highest reported flow rate was 116 µl/min. In this study, an efficient and multifunctional microfluidic device is introduced which is capable of performing pumping, mixing, and delivering higher flow rate than the one reported in [12].

DESIGN

Computer-aided design software (AutoCAD, Autodesk Inc., San Rafael, CA, USA) was used to design the desired microfluidic device. The device is basically a valve-less rectification micropump that employs rectification geometry for rectification as well as mixing due to the bifurcation microfluidic diodicity and its own configuration. Bifurcation geometries are placed on both sides of a 10 mm pump chamber. The way the bifurcation geometries are placed has formed two inlets and one outlet (2 mm diameter). The bifurcation geometry has one primary channel and two secondary channels. Alignment guides were implemented in the design to be used in the alignment process of the Piezoelectric Transducer (PZT) over the pump chamber, please see figure 1 for more details.

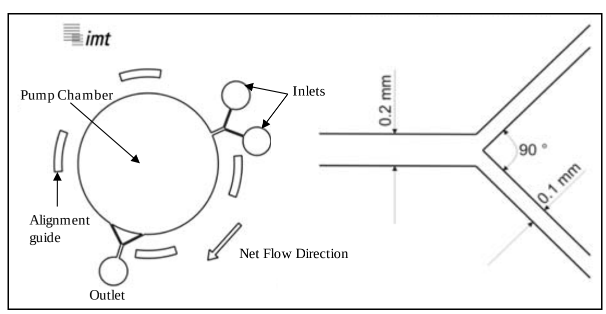

Figure 1: The design of the multifunctional microfluidic device.

FABRICATION

Optical lithography was used as the main fabrication method in this work, and a PZT was used to actuate the micropump. A 700 µm thick soda-lime glass was used as a substrate for the SU-8 negative master. After cleaning and dehydration (1 h at 120 °C), the substrate was activated with oxygen plasma (plasma activate flecto 10USB, Plasma Technology, Germany). Directly after the first SU-8 layer (SU-8 5 from MicroChem, Corp., Newton, MA, USA) is spun on at 3000 rpm for 30 s and dried for 10 min at 95 °C. This layer, acting both as an adhesion promoter and base layer for the following SU-8 layer structures, was flood exposed to UV-light and baked at 95 °C for 10 min. Before spin coating of the structure layer the base layer was activated in oxygen plasma. SU-8 50 was applied at 1200 rpm, leveled and dried at 95 °C for 2 h. The same process steps were repeated – including an additional hour of drying – in order to attain a total layer thickness of 230 µm. Then, the substrate was exposed to UV-light for 100 s. A post exposure bake follows for 20 min at 95 °C. The fabrication of the negative master concludes with the development in propylene glycol methyl ether acetate (PGMEA, MicroChem Corporation, Newton, MA, USA). To seal the pump chamber and channels, a 700 µm thick soda-lime glass was chemically etched (for ports) and then glued to the SU-8 structure using silicon glue (RS Components, Mörfelden-Walldorf, Germany) dispensed from micro dispenser. Finally, a 12 mm PZT was glued to the etched glass. The etched glass area under the PZT was filled with Polydimethylsiloxane (PDMS) to act as a membrane. Figure 2 shows a cross sectional view of the microfluidic device after the fabrication process.

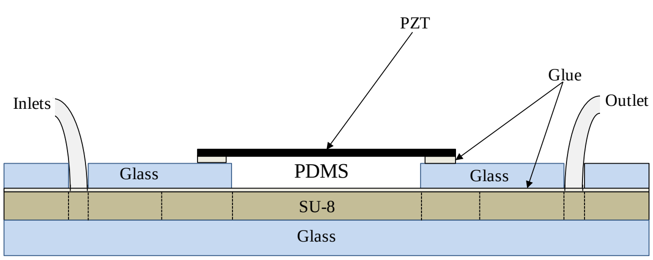

Figure 2: A cross sectional view of the multifunctional microfluidic device

EXPRIMENTAL APPARATUS

Figure 3 shows the experimental apparatus which was 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. Flow rate measurements were conducted based on the bubble tracking method [13]. 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.

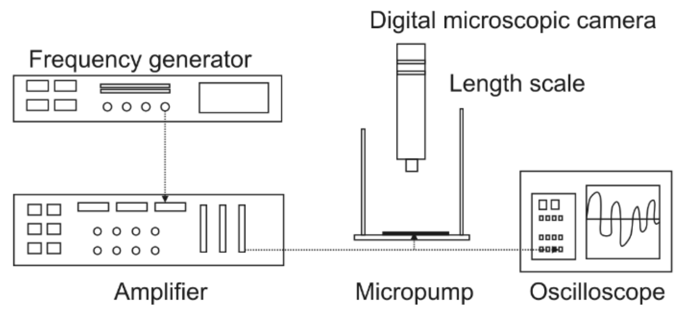

Figure 3: The experimental apparatus which used to test the multi functional microfluidic device.

RESULTS AND DISCUSSIONS

The microfluidic device was tested against a low range of frequency (0-300 Hz), and the results are presented in Figure 1. The results show that the flow rate is monotonically increased with the frequency and, as a results, the maximum flow rate is occurred at 300 Hz. The maximum flow rate and associated maximum back pressure are 472 µl/min and 4.3 kPa, respectively.

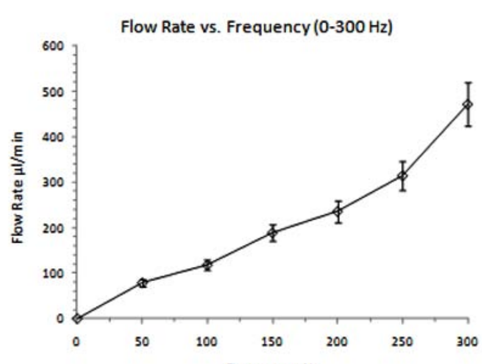

Figure 4: The flow rate of the microfluidic device as a function of the actuator frequency

To test the mixing function of the device, clear ethanol was introduced at one inlet while inked ethanol was introduced at the second inlet. Parallel layers were clearly observed at the inlet regions and mixing was visually observed at the outlet, please see Figure 5.

The results show that valve-less rectification micropump based on bifurcation geometry can be employed as a multifunctional microfluidic device to deliver both pumping and mixing functions at the same time. The natural configuration and high microfluidic diodicity of the bifurcation geometry have promoted both mixing and pumping functions at the same time. The presented device is self primed and can pump ethanol without a priming step.

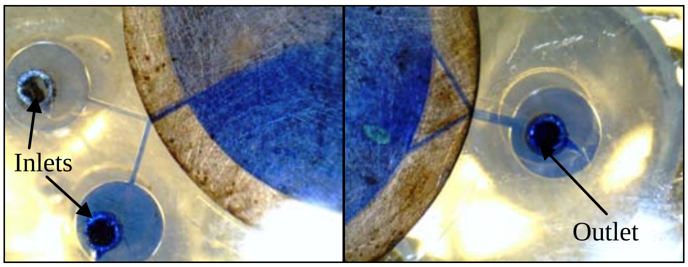

Figure 5: The mixing and pumping functions of the microfluidic device: Parallel flow layers are visible at the inlets and mixing is visually observed at the outlet

CONCLUSION

An efficient Multifunctional microfluidic device is designed, fabricated, and tested, where it can perform pumping and mixing at the same time. The device is basically a valve-less rectification micropump based on bifurcation geometry. The device shares the advantages of the valve-less rectification micropump and adds the mixing function. It is easily fabricated by using optical lithography, and it delivers favorable flow rates at low frequencies. Additionally, it is a self priming device that required no pre-steps for operation.

ACKNOWLEDGMENTS

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

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