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PIEZO-ACTUATED VALVELESS MICROPUMPS FOR MICRO-TOTAL ANALYSIS SYSTEMS

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ABSTRACT

In this work, a Piezo actuated Valveless micropump is proposed for applications in Micro-Total Analysis Systems (µTAS) and Lab-on-a-Chip. Flow rectification in the micropump has been brought about with the use of a diffuser element. The device is fabricated on PDMS-Glass substrate with the glass acting as the diaphragm. A PZT disc is integrated with the setup for actuation. The micropump has been characterized for its dynamic behavior, flow characteristics, and pressure. It was found that the maximum flow rate for the micropump was obtained at low frequency which makes it usable for practical µTAS applications.

INTRODUCTION

Micro-Total Analysis Systems (µTAS) are miniaturized chemical or biological anaysis systems which basically derive their functionalities by virtue of their miniaturization, i.e all biosensing processes that are presently carried out on macro-scale anaysis systems are miniaturised and integrated onto a single chip, which is called a Micro-Total Analysis System [1]. There are several components which can be integrated with the µTAS, such as micromechanical systems, microphotonics, microthermal systems, microfluidics, among others, depending upon their applications. However, in order to enable handling of smaller sample volumes conveniently and for the transportation of the biofluid into the system for detection, it is absolutely essential to integrate suitable microfluidics component with the µTAS. Micropumps play an important role in µTAS, as they are used for obtaining continuous biofluid movement through the system through direct transformation of non-mechanical or mechanical energy for fluid actuation. With the help of these micropumps, fluid transported into the µTAS is controlled to the order of nanolitres and sometimes picolitres, which is essential for carrying out sensitive biodetections. Several works have been carried out to model [2] and also fabricate [3,4] micropumps for fluid actuation at microlevels.

This paper presents the synthesis of a novel three layer Piezoelectric Actuated Valveless Micropump (PAVM) for Lab-on-a-Chip and µTAS applications. PAVM is an attractive device to be used as a microfluid actuator for small flow rates. Herein, flow rectification is brought about by the differential pressure drop across the nozzle and the diffuser elements that are designed with the micropump [5]. The main advantage of using a three layer PAVM compared to the other traditional valveless micropumps is the feasibility of fabricating a multilayer µTAS and also the ease of integration of the micropump with other complimentary modules.

The micropump is fabricated on PDMS-Glass material platform and is internally hybrid integrated with the optical detection system of the proposed µTAS. Experimental verification of the micropump behavior has been carried out on the integrated system using different fluids and the results show that this device is highly useful for µTAS applications and integration with portable Lab-on-a-Chip systems.

FABRICATION OF PAVM

The micropump discussed herein is a three layer device. The microfluidic channel and the reservoir made on PDMS material platform, referred to as channel layer from now on. The PDMS was bonded with glass membrane which was used for actuation. The Piezo disc was attached to the glass membrane using a conductive epoxy.

The mould for the PDMS microfluidic channel was fabricated on SU8-on-Silicon. SU8 negative photoresist was patterned on silicon using standard lithography process. SU8 (2015

Microchem) patterned on Silicon was used the master mould for PDMS. For the photolithography, the silicon wafers were initially cleaned with acetone and Piranha Solution. The following specifications, given in Table 1, were used for SU8 lithography on Silicon.

After the preparation of the Silicon mould for PDMS, in order to prevent the adhesion of PDMS with the substrate during subsequent curing, vapor phase silanization was then carried out on the mould, by heating it with 1 ml of (Tridecafluoro-1,1,2,2-etrahydrooctyl)-1-Trichlorosilane (United Chemicals Inc., USA) at 80 ^{o}C in a closed chamber. Thereafter, 10:1 ratio of the pre-polymer and the curing agent (Sylgard 184, Dow Corning) was mixed well and de-gassified. The mixture was then poured onto the silicon mould and baked at 80 ^{o}C for 2 hours. The PDMS was then removed from the mould and in this way, the patterns on the silicon mould are stamped on the PDMS. The main advantages of using Silicon mould is that the PDMS obtained upon curing is flat which renders the adhesion of the substrate subsequently with other substrates easier.

Operation	Specifications
Pre-baking	150 ^{o}C for 300 s
Spin Coating	Step (i) 500 rpm, 10 s Step (ii) 1250 rpm , 30 s
Soft baking	95 ^{o}C , 90s
UV exposure	Lamp power 150 mJ/cm^2 , 10 s
Post-Exposure Baking	95 ^{o}C, 240 s
Developing	180 s
Hard baking	100 ^{o}C , 900 s

Table 1: Photolithography parameters for SU8 patterning

For external tube connections, ports are created on the PDMS channel layer after removal from the mould. A thin glass slide of 150 µm thickness was spun coated with the prepolymer-curing agent mixture at 1500 rpm and the setup was semicured at 90 ^{o}C for 4 minutes. The channel layer PDMS, was then gently bonded with the semicured PDMS-on-glass with the application of slight pressure. The setup was again cured, to permanently seal the glass with the PDMS channel layer. PZT disc (Piezo systems Inc., MA) was then aligned with the channel reservoir and bonded on top of the glass slide using a conductive epoxy. Electrodes were connected with both the sides of the PZT disc using conductive epoxy.

EXPERIMENTAL CHARACTERIZATION OF THE MICROPUMP

The experiments carried out with the micropump was aimed at the measurement of the flow characteristics, pressure characteristics and the vibrational behavior of the actuator system. A signal generator was used for the voltage input and this was connected with a high voltage amplifier circuit with a gain of 30, for the micropump, given that significant micropump deflection and hence the fluid motion was obtained only for actuation voltages of more than 100 V_{pp}.

Measurement of pump deflection

The deflection of the PZT actuator was measured using a single point Laser Doppler Vibrometer system [6]. The setup is as shown in Figure 1.

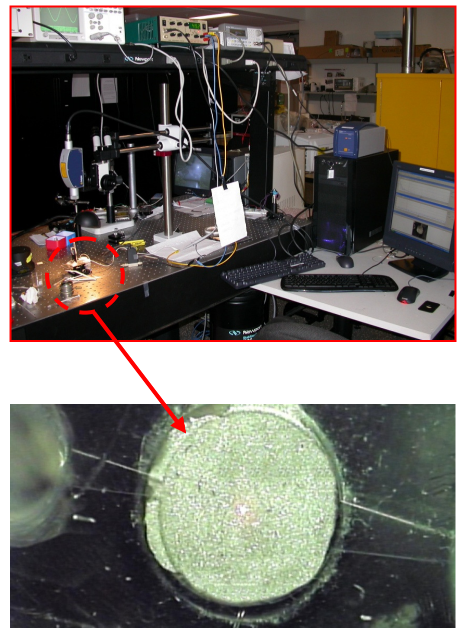


Figure 1: Experimental setup for the measurement of pump deflection using a single point Laser Doppler Vibrometer

The micropump was tested for the deflection with three different fluids, namely, air, water and oil. For the deflection measurements, it was important that there are no gas bubbles that are formed in the liquids and therefore, the liquids were slowly injected into the system.

The results are as shown in Figure 2. The maximum deflection is obtained without any liquid in the channels. The deflection was also proportional to the density of the working fluid.

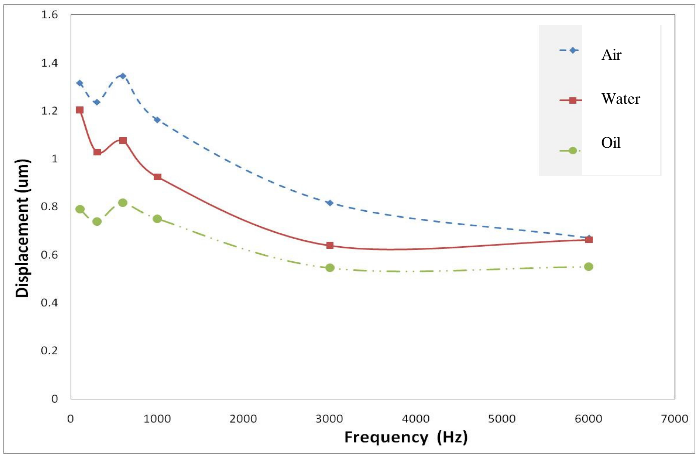


Figure 2: Plot of central pump deflection at different operating frequencies in different media

Though the maximum deflection of the pump is expected to occur at its natural frequency, high frequencies would not be useful for the pumping due to the effects of cavitation at such frequencies.

Measurement of pump pressure

In order to measure the pressure inside the micropump chamber, the pressure sensor was directly integrated to pump chamber with a microfluidic connection. The experimental setup is as shown in Figure 3.

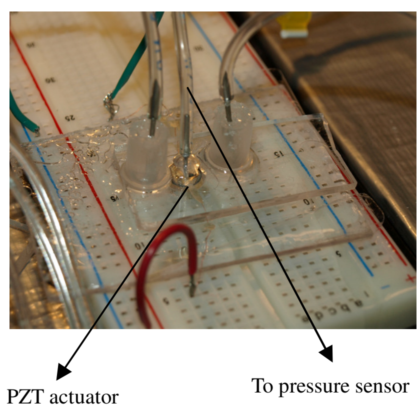
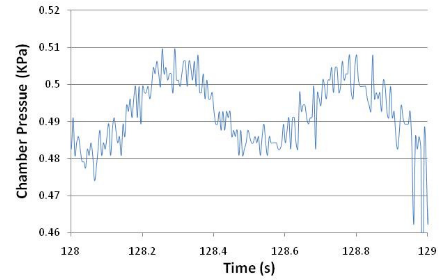
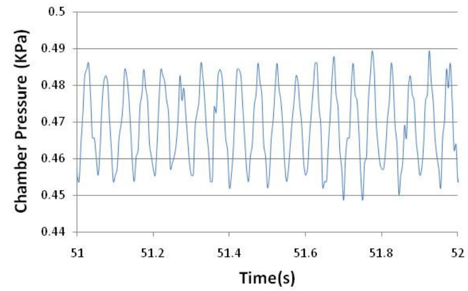


Figure 3: Chamber pressure measurement setup for micropump

The pressure measurement was carried out using pressure sensor (Servoflo, MA) The time-dependent variation in the chamber pressure was recorded for different actuating frequencies and voltages. As an example, Figure 4 shows the time dependent variation of pressure inside the micropump chamber for two different actuation frequencies.



(a) 2 Hz



(b) 20 Hz

Figure 4: Plot of the variation of micropump chamber pressure with time for an actuating voltage of 300 V

Measurement of flow rate

For the flow rate measurement, the outlet channel of the micropump was connected with the flowmeter (Sensirion SLG1430A). The flow rate was recorded with time for different frequencies for the maximum pump deflection which was obtained at 300 V, a sample plot is shown in Figure 5 for an actuating frequency of 3 Hz. The net flow was obtained by integration of the flow rate in the positive and the negative flow directions over time, as presented in Figure 6.

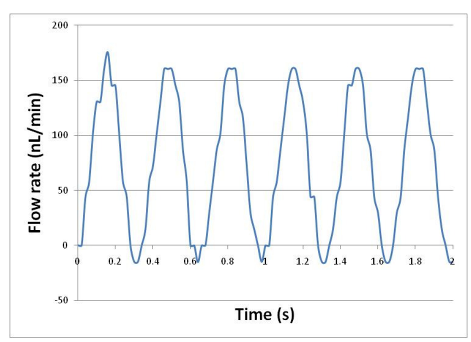


Figure 5: Flow rate vs. Time for a pumping frequency of 3 Hz

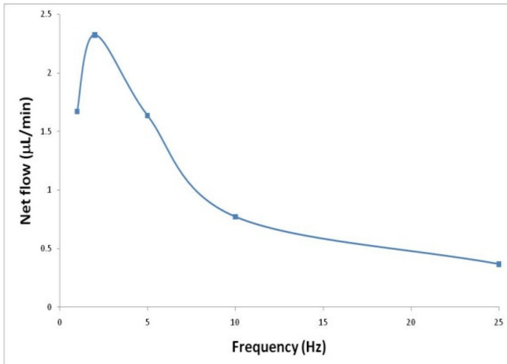


Figure 6: Plot of the net flow pumped through the micropump for different actuating frequencies

The flow rate is a function of the deflection and the pressure inside the chamber. Though the maximum deflection is obtained at the natural frequency of the oscillating system, the operating frequency would not be suitable for pumping, because at higher frequencies cavitation effects set thereby drastically reducing the flow rate and the performance of the micropumps. For the present system, the natural frequency was found to be 75 KHz.
The experiments were repeated three times. The maximum flow rate is obtained for a frequency of 2 Hz, beyond which the flow rate decreases with increase in frequency. This could probably be because of the effect of cavitation at higher pump frequencies. From the pressure measurement within the chamber, it was found that the maximum mean chamber is obtained at lower frequencies which favors higher flow rate. Thus, the flow obtained with a micropump is a direct function of the chamber pressure that is obtained by the actuation of the diaphragm.

CONCLUSION

In this work, a Piezo actuated valveless micropump has been presented for integration with the Micro-Total Analysis System. The micropump has been tested for its flow directing capabilities and the flow parameters such as chamber pressure, frequency of vibration and flow rate have been characterized. The advantages of the presented micropump are valveless configuration, robustness, ease of integration packaging, feasibility of cost effective batch fabrication, precise flow characteristics, and immunity to the nature of fluid transported which makes it ideal for biological applications.

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