Low Cost Fabrication of a Piezoelectric Actuated Valveless Micropump

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Abstract*– In this work, a piezoelectric valveless micropump is fabricated using a low-cost technique. A pattern cut in an adhesive is used to generate the diffuser/nozzle structures and the chamber. Two borosilicate glasses enclose the pattern on both sides. A 150 µm glass cover works as a 20 mm-piezo-driven membrane and the inlet and outlet are made by drilling holes through a 1mm glass slide which serve, simultaneously, as substrate for the device. The built micropump is able to handle a maximum pressure head of 21.5 mm of water, and a maximum flowrate of 3.74 µL/s. The design works as intended and the chosen materials proved to be suitable for the application. The process fulfilled the targeted cost and time of fabrication.

Keywords—micropump, valveless, low cost, microfluidics, piezoelectric.

I. Introduction

Microfluidics is a multidisciplinary field, concerned about the design of systems that handle small volumes of fluids. Some of the applications are inkjet print heads, DNA chips, lab on chip technology, micro-propulsion, drug delivery, and micro thermal technology [1].

In this work, a piezoelectric micropump was built using a low-cost fabrication technique. This technique was called GAG (glass-adhesive-glass) and consists of a patterned thin adhesive enclosed by two glasses. Once fabricated, an experimental setup was used in order to determine the pressure-flow characteristic curve of the micropump.

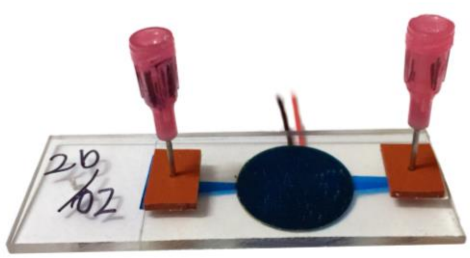

Fig. 1 Fabricated piezoelectric actuated valveless pump.

II. Principle of Operation

The energy supply, as it was stated before, is achieved by the means of a PZT piezoelectric material. Concretely, the inverse piezoelectric effect states that these materials, when subjected to an electrical field, become proportionally strained. The simplified linear piezoelectric constitutive strain-charge relation, assuming no residual stress and radial strain only, is:

$$S_1 = d_{31}E_3 \tag{1}$$

where S is the mechanical strain, d is the piezoelectric strain coefficient, and E is the applied electric field.

The electric field is described by Maxwell's laws and the geometry of the system:

$$E = -\nabla V = \frac{V}{t_p} \tag{2}$$

where V is the voltage applied and t_p is the width of the piezoelectric disk.

The elastic behavior of the thin glass is described by Newton's second law [2]:

$$\rho \frac{\partial^2 u}{\partial t^2} - \nabla \cdot \sigma = F_v \tag{3}$$

where ρ is the density of the solid, $\mathbf{u}$ is the solid displacement vector, $\boldsymbol{\sigma}$ is the stress tensor and $\mathbf{F}_v$ is the body force per unit volume.

About incompressible fluid motion, considering irrotational flow, steady state, and after considering the contribution of any external forces, the system can be described as follows:

$$\left(\frac{u^2}{2} + \frac{p}{\rho} + gz\right)_1 - \left(\frac{u^2}{2} + \frac{p}{\rho} + gz\right)_2 = -h_P + h_f + h_L \tag{4}$$

where ρ is the density of the fluid, u is the fluid velocity, p is the pressure, h_P is the sum of the head gains of the pumps, h_f is the sum of the head losses because of pipe friction and h_L is the sum of the head losses in the accessories.

Then, the inlet and outlet connection are considered both accessories of the nozzle/diffuser type. The distinction between these behaviors in each connection is determined only by the direction of flow and its own geometry. As a pressure differential is exerted by the glass membrane, the flow from inlet and outlet to the center changes, as seen in Fig. 2. With the membrane going up, the fluid from both accessories goes to the center, but the design assures that the inlet acts with diffuser behavior, and the outlet as a nozzle. Because the losses can be modeled as:

$$h_L = k\frac{u^2}{2} \tag{5}$$

and the value of k is usually ten times bigger for a nozzle, the pressure drop is bigger in the outlet and more fluid ends up entering from the inlet than from the other side. The exact opposite happens when the membrane goes down, completing the flow cycle.

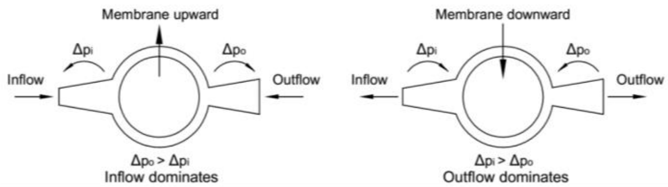

Fig. 2 Nozzle/diffuser behavior during a downward and upward movement of the membrane.

III. Manufacturing Process

The main motivation for the selection of the manufacturing process was to get a low-cost and repeatable fabrication technique. This was achieved through the GAG technique which uses a combination of glass and adhesive layers to create a flow path. In order to work as intended, one of the layers of glass needs to be very thin to have a wider range of elastic motion, thus exhibiting a typical membrane behavior when properly excited. The other piece of glass must be thicker for structural purposes. The thickness of the chosen adhesive sets the transversal area of flow. In this case the thicknesses of the glass layers were 980µm and 155µm, and 205µm thick for the adhesive layer.

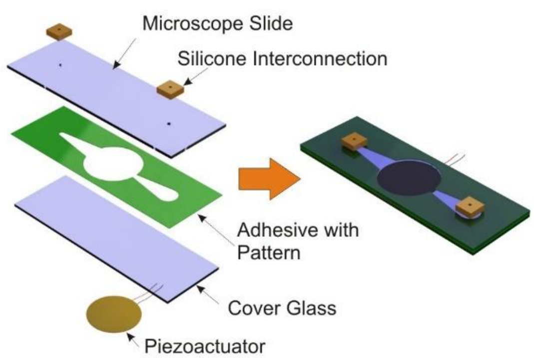

Fig. 3 Assembly of the piezoelectric valveless micropump.

The general steps to produce a complete, functional micro pump are described here:

1. The pump's design is cut onto an adhesive, using a computer controlled electronic cutting machine.
2. Two holes are drilled on the thick glass, with a position coincident with the inlet and outlet of the design.
3. One side of the adhesive is then pressed onto the previously cleaned thick glass.
4. The thin glass −stored in clean and dry conditions− is placed over the reverse side of the adhesive, applying pressure
5. The piezoelectric piece is glued to the thin glass, on the central position of the pump. The curing time of the glue is 24 hours.

IV. Results

In order to obtain the characteristic curve of the micropump and to demonstrate the feasibility of the chosen micro-fabrication technique, an experimental setup was built. The pumped volume over time was measured as shown in Fig. 4.

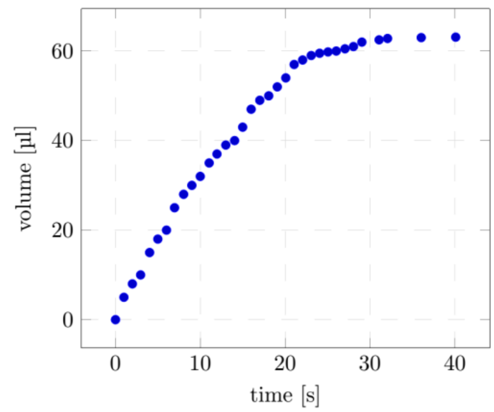

Fig. 4 Pumped volume over time.

The micropump was connected to two reservoirs, one in the inlet and one in the outlet. At the beginning, when the micropump is not operating, both reservoirs had the same water level. When the micropump starts pumping the fluid, the pressure head is minimum and the maximum flow rate is obtained. Then, the pressure head rises over time and the flowrate becomes zero at a maximum pressure head as shown in Fig.5.

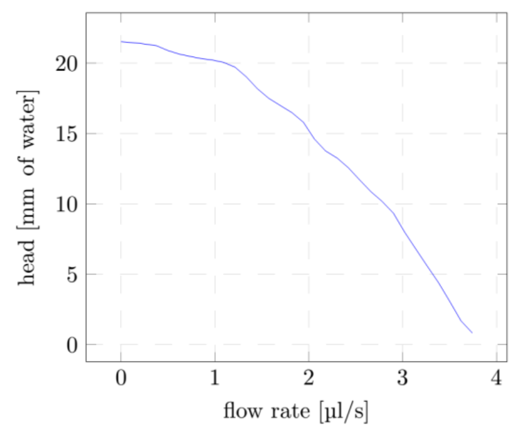

Fig. 5 Characteristic curve of micropump.

V. Conclusions

The GAG technique has proved to be suitable for the prototyping of active microfluidic devices, such as the piezoelectric valveless micropump built in this research.

The micropump shows the usual behavior of a pump, with a maximum pressure head of 21.5 mm of water, and a maximum flowrate of 3.74 µL/s.

References

[1] D. J. Laser and J. G. Santiago, *A review of micropumps*, Journal of Micromechanics and Microengineering, **vol. 14**, no. 6, pp. R35–R64, (2004)

[2] J.A. Pelesko and D.H. Bernstein. *Modeling Mems and Nems*. CRC press, (2002)