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Development of microvalves for gas flow control in micronozzles using PVDF piezoelectric polymer

R S Wiederkehr[1], M C Salvadori[1], F T Degasperi[2] and M Cattani[1]

[1] Institute of Physics, University of São Paulo,
CP 66318, CEP 05315-970, São Paulo, SP, Brazil

[2] Faculdade de Tecnologia de São Paulo, Centro Estadual de
Educação Tecnológica Paula Souza – CEETEPS – UNESP – São Paulo, SP, Brazil

E-mail: rodrigosergio@hotmail.com

Abstract. This work describes a fabrication and test sequence of microvalves installed on micronozzles. The technique used to fabricate the micronozzles was powder blasting. The microvalves are actuators made from PVDF (polivinylidene fluoride), that is a piezoelectric polymer. The micronozzles have convergent-divergent shape with external diameter of 1mm and throat around 230μm. The polymer have low piezoelectric coefficient, for this reason a bimorph structure with dimensions of 2mm width and 4mm of length was build (two piezoelectric sheets were glued together with opposite polarization). Both sheets are recovered with a conductor thin film used as electrodes. Applying a voltage between the electrodes one sheet expands while the other contracts and this generate a vertical movement to the entire actuator. Appling +300V DC between the electrodes the volume flux rate, for a pressure ratio of 0.5, was 0.36 sccm. Applying -200V DC between the electrodes (that means it closed) the volume flux rate was 0.32 sccm, defining a possible range of flow between 0.32 and 0.36 sccm. The third measurement was performed using AC voltage (200V AC with frequency of 1Hz), where the actuator was oscillating. For pressure ratio of 0.5, the flow rate was 0.62 sccm.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Piezoelectric actuators are very often used to fabricate microvalves because of the viability to obtain an opening and closing movement by changing the direction of the electric field applied on it. The actuators can be built in two different modes: unimorph or bimorph. The unimorph device is a piezoelectric layer bonded to a non piezoelectric substrate [1] and a bimorph actuator is two piezoelectric layers of different polarization glued together [2].

Most of the design and fabrication techniques known uses piezoelectric ceramics as material due the high piezoelectric coefficient [2,3]. The disadvantage of using the ceramic is their high cost and the difficulty to cut them to obtain the desired size and shape. Using polymer as the material to fabricate the actuator it is possible to have devices lightweight, with low cost and with complex design [4]. Poli(vinylidene fluoride) was used because it exhibits the strongest piezoelectric coefficients when comparing to others polymeric piezoelectric materials [5].

In this paper we describe the fabrication sequence of a bimorph PVDF actuator used as a microvalve to control the gas flux through a micronozzle present in a glass substrate. The micronozzle was convergent-divergent with a throat diameter of 230 μm and an external diameter entrance of 1mm. The tests were performed in a gas line under low pressures (inlet pressure was kept constant as 266 Pa) with different values of applied voltage. In addition, similar flow tests were performed with a micronozzle without actuator (uncovered) to compare the results.

2. Fabrication sequence

2.1. Development of microactuators using poli(vinylidene fluoride) piezoelectric polymer

The actuators were fabricated using polymer sheets from Piezotech S.A. [6] with 25µm thick, already polarized and coated with a conducting thin film as electrode in one side. PVDF presents piezoelectric proprieties only if its molecules are mainly oriented in the same direction (state known as ß phase) [5]. To develop the bimorph structure, low viscous epoxy glue, presenting good adhesion with the PVDF, was used to glue two pieces of different polarization. The first step was to cut two squares of 30 x 30 mm^2 of PVDF sheet to be glued to each other. To obtain a thin layer of glue, an epoxy viscous composite (Araldit Cristal®) was diluted in xylene (0.6g of epoxy in 0.2ml of xylene). Using a spinner (5000rpm for 10s) it was possible to deposit a homogeneous layer of glue in the surface of the square sheet that was clamped in a silicon substrate and then join the two parts. It's important to note that, to obtain a bimorph structure, the polymer squares must be glue with their polarization in the opposite directions (so when the electric field is applied through the electrodes one layer will contract while the other layer will expand causing a deflection on the whole device). With a sharp knife the bimorph structure was cut in rectangles with 3 mm width and 6 mm length. The size and format chosen created a device with good deflection and enough force to be used as microvalve in a nozzle with a pressure difference of 266 Pa between the inlet and outlet.

2.2. Fabrication of micronozzles in glass substrate using the powder blasting technique

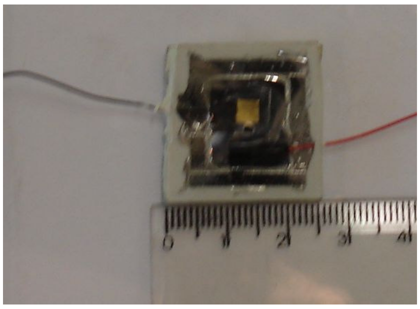
Powder blasting has been used for glass decoration and to remove layers of paint and clean dirt from metallic devices. If the glass surface is masked (that means expose just small areas that will be removed and protect the remained area) it's possible to fabricate very small structures.

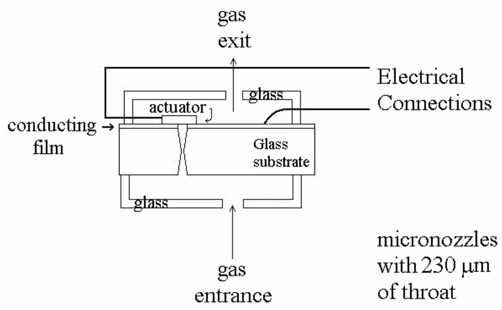
The material to make the mask must have low erosion rate, capability and accuracy in patterning. Several masks were tested by different research groups like polymer mask and metallic thin film mask [7,8]. But, to use these materials as masks for powder blasting, it is necessary to deposit them and microfabricate structures for each surface to be eroded. To simplify the method we chose to use a metal plate mask (like ref.[8]). For this work purpose, it was possible to transfer the desired patterns (circular hole) just using a drill.

The fabrication process of the micronozzles was divided in 5 steps. Initially (I) a metal mask was fabricated with holes of 1mm diameter (made with a drill); then (II) the mask was fixed in a glass substrate with 25x25 mm^2 and 1.2mm thick, using a plastic glue; in the sequence, (III) the powder blasting erosion was performed; then (IV) the mask was transferred to the back side of the glass substrate and a new powder blasting erosion was performed, in this point it is necessary to align the mask so as to coincide both erosion; and, finally, (V) to remove the mask and clean the substrate.

2.3. Microvalve installation

To install the microvalve on the glass substrate, it was necessary to deposit a conductive film on the substrate surface that was to be in contact with the bimorph PVDF structure. A platinum film 200 nm thick was deposited by filtered vacuum arc. Using an insulate tape the actuator was clamped and aligned with the micronozzle. In this way, one of the actuator contacts was the substrate platinum film, since it was in mechanical contact with the lower electrode of the bimorph structure. And the second actuator contact was the top electrode of the bimorph structure. Wire connections were glued in the substrate platinum film and in the top electrode of the actuator, using conductive glue. The last step was the encapsulation of the device using a glass plates with a circular hole of 2mm diameter. Figure 1(a) shows the upside view and figure 1(b) shows the schematic draw of the device (lateral view) after been mounted.





(a) (b)

Figure 1: (a) Upside view of the microvalve mounted. In the borders the white epoxy glue was used to seal and prevent leaks (the scale of the rules is in centimeter). (b) Scheme of the complete device. The gas enters in one side pass by the micronozzle, the bimorph actuator and quit by the opposite side. The scheme is out of scale.

3. Microvalve Operation with DC and AC Voltage

In this section we present the mechanical response of the microvalve described. When a positive DC voltage is applied on the top electrode, the actuator opens (it moves vertically in the direction of the top electrode). When a negative DC voltage is applied to the top electrode, the actuator close (it moves vertically in the direction of the lower electrode). Appling an AC voltage the actuator oscillates according to the voltage frequency.

4. Characterization of the microvalve using a gas flow line

The device was characterized keeping at a constant pressure the inlet of the microvalve and measuring the gas flow rate at the outlet. The gas flow tests were performed using a maximum pressure difference of 266 Pa.

A large chamber X (V_X = 263 liters) was kept in the same pressure (P_X = 266 Pa) during all the experiments and was in contact with the device entrance. A small chamber Y (V_Y = 0.343 liters), initially in a lower pressure ($P_X > P_Y = 4$ Pa), is connected with chamber X through the device to be characterized. The gas used in all measurements was the atmospheric air. Each chamber was monitored with a pressure pirani sensor (model APG-M from BOC Edwards). A Data Acquisition Switch from Agilent (model 34970A) was used to acquire the chambers pressure and ambient temperature from the sensors as function of the time (t). The data were stored in a computer.

5. Data analyses and results

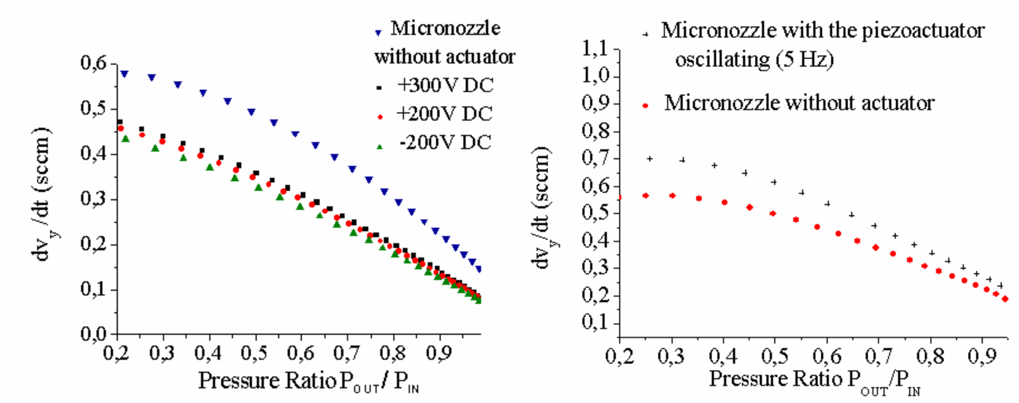
The data collected from the measurements were basically the chamber Y pressure (P_Y) as function of the time (t). In the range of pressures used in this work ($4 < P < 266$ Pa), the air can be considered as an ideal gas. In this way the following equation was used:

$$\frac{dv_y}{dt} = \frac{M_{air} V_Y}{\rho_{airS} RT} \frac{dP_Y}{dt} \qquad (1)$$

where dv_y/dt is the standard volume flow rate thought the device, M_{air} is the average molecular mass of the air, ρ_{airS} is the air density in standard conditions of temperature and pressure, R is the universal gas constant and T is the ambient temperature.

The chamber Y pressure (P_Y) as function of the time (t) has been adjusted by a polynomial best fit and the derivate dP_Y/dt has been calculated. With this result and the measured values of V_Y and T, the standard volume rate (dv_Y/dt) thought the device was obtained as function of the pressure ratio P_{out}/P_{in}, where P_{out} is the pressure in the chamber Y and P_{in} is the pressure in the chamber X

Figure 2(a) shows the results of dv_y/dt as function of P_{out}/P_{in} for three different actuation conditions: applying +300V DC, +200V DC, −200V DC on the actuator electrodes and also for the case where the micronozzle is without actuator. The micronozzle used has throat of 230µm and external diameter of 1mm. Figure 2(b) shows the results of dv_y/dt as function of P_{out}/P_{in} for the actuation conditions: applying 200V AC voltage with 5Hz of frequency and the case where the micronozzle is without actuator. The standard volume rates (dv_Y/dt) are in sccm (stander cubic centimeter per minute).



(a) (b)

Figure 2: (a) Results of the standard volume rates dv_Y/dt as function of P_{out}/P_{in} for three different actuation conditions and for the case where the micronozzle is without actuator. (b) Standard volumes rates for the case applying an AC voltage with 5Hz of frequency. The standard volume rates (dv_Y/dt) are in sccm (stander cubic centimeter per minute). The inlet pressure was kept constant as 266 Pa.

6. Conclusions

In this work was presented a device fabrication that allows controlling precisely the flow rate through it. The device was a composition of micronozzle fabricated in glass substrate and a piezoelectric actuator. The actuation was controlled applying DC and AC voltages on the actuators electrodes. For the pressure ratio P_{out}/P_{in} of 0.5, the standard volume rates dv_Y/dt for the open position +300V DC was 0.36 sccm, for −200V DC was 0.32 sccm and for 200V AC was 0.62 sccm.

Acknowledgments

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