BEHAVIORAL MODELING OF A LTCC MICROFLUIDIC SWITCH

Reinaldo Rosa, Antonio Seabra, Mario Gongora-Rubio

reinaldorosa@usp.br; acseabra@lsi.usp.br; gongoram@ipt.br;

Abstract: *This work presents the behavioral modeling developed for different components necessary for the construction of an electromagnetically actuable microvalve, associated to the use of a flexible membrane. Theoretical models have been developed for the description of fluid flow in microchannels, especially channels with rectangular cross sections, used in the construction of most microchannels used in microfluidics. The model for describing the deformation experienced by a PDMS microponte was developed, allowing to estimate the elastic stiffness for several membranes developed in this work. Using the microfluidic model, a study of microchannels, it was possible to estimate the hydraulic resistance offered by microchannels with sub-millimeter dimensions, allowing to evaluate the relation between inlet pressure and the corresponding outlet flow. It was possible to verify analytically that for a specific working range (flow rates in the range of 0.2 to 6 mL / min using pressures ranging from 0 to 30 kPa), channels with 1 cm in length and 200 μm in height should have the width ranging from 300 μm to 500 μm in order to operate in the range of interest established by his actuation on real environments. Using a 2 cm long and 300 μm channel, the height value can be between 200 μm to 400 μm, allowing miniaturizing the final device, ensuring the desired operating range.*

Key-Words: *microswitch; LTCC; PDMS; microvalves*

Introduction: Several miniaturized systems have been developed due to the high level of performance related to the functionalities applied to areas such as medicine, biology and chemistry. The ability to create structures and tracings in sub-millimeter scales, through microelectronics manufacturing methods, has promoted the development of microdevices capable of transporting and manipulating fluids in microstructures, reaching scales of comparable length at the cellular or even lower level, allowing analysis and detection of very small quantities of the species of interest. Essentially, microfluidics is a field dedicated to the miniaturization of fluidic conduits and manipulation of these fluids, allowing the integration of previously incompatible systems. The first microfluidic systems developed [1,2], although quite memorable, did not represent completely integrated miniaturized systems, as later found in the literature [3].

Experimental: The forces applied to the elements of the fluid originate with the stress of the fluid exerted on the surface, given by the stress tensor, $\overleftrightarrow{\boldsymbol{\sigma}}$, in addition to the external forces applied on the element, $\boldsymbol{f}$. Figure 1 presents the standard model considered in this work for the description of the most common microchannels found in microfluidic systems. The rectangular cross section with length l, width w and height h and the circular cross section with length l, and radius r were the most used surfaces in hydrodynamic models and the development of microchannels in microfluidic systems.

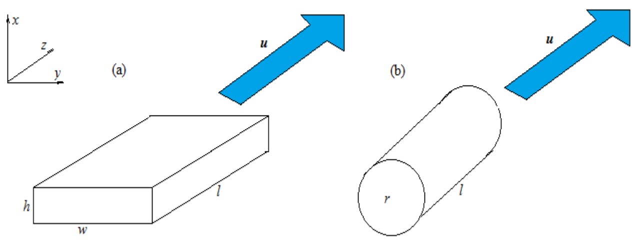

Figure 1: Model of a (a) rectangular (b) circular channel through which the fluid travels with velocity $\boldsymbol{u}$.

The relationship between the inlet pressure and the flow rate in the system is given by, ρ is the fluid density [kg / m³], η is the viscosity of the fluid [Pa.s] and p is the pressure applied to the fluid [Pa]:

$$\Delta p = r_H Q$$

For a circular channel the hydraulic resistance is given by:

$$r_H = \frac{8l\eta}{\pi r^{\mathbf{4}}}$$

For a rectangular channel the hydraulic resistance is given by:

$$r_H = \frac{12\eta l}{wh^3\left\{1 - \frac{192}{\pi^5}\frac{h}{w}\langle\sum_{n=1,3,5}^{n=\infty}\frac{1}{n^5}\tanh\frac{n\pi w}{2h}\rangle\right\}}$$

Results and discussion: For comparative purposes consider a circular channel, 13 centimeters in length with radius ranging from 0.08 to 0.24 millimeters, and a rectangular channel 13 centimeters long, 200 micrometers in height and width ranging from 0.1 to 0.9 millimeters carrying water (viscosity 0.001 Pa/s and density 1000 kg/m³) the curves describing the behavior of the hydraulic resistances, given in [Pa.s/m³], offered by these channels in function of the variable parameters were obtained using computational simulation based on the MATLAB software (figure 2). In the case of the circular channel, the associated hydraulic resistance decreases from 6.0 GPa.s /m³ to about zero when the radius increases from 0.5 mm to 2.0 mm. The rectangular channel resistance is reduced from 85,000 GPa.s /m³ to about 2000 GPa.s /m³ when the width increases from 0.1 mm to 0.9 mm.

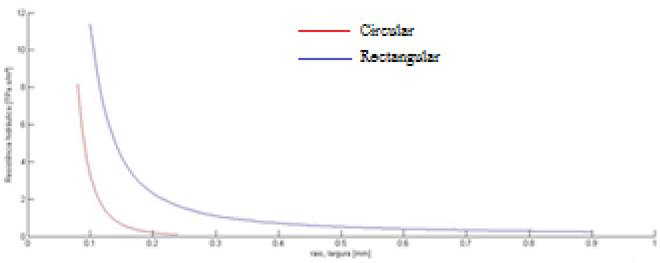

Figure 2: Reduction in the resistance of a circular channel as a function of the radius (red curve), and a rectangular channel as a function of the width (blue line) considering water as the fluid.

Conclusion: It is concluded from this analysis that it is possible to determine mathematically the hydraulic resistance offered by a channel with a rectangular cross-section, considering the transport of an incompressible fluid and pressure and flow ranges for which the flow is laminar. Figure 2 presents the simulation for the hydraulic resistance offered by a circular channel and a rectangular channel, as a function of a parameter associated to the corresponding cross-sectional dimension. In both cases, the hydraulic resistance is reduced as the cross section of the channel is increased.

References and acknowledgements:

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