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SIMULATION OF MICRODIODES

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Abstract

A brief presentation is given on the field of application of microfluidic devices, and their main properties are mentioned in the introduction. This paper deals with the numerical investigations of the viscous incompressible flow in micro devices using finite element modelling. After a validation of the numerical model for micro scale, the rectifying ability of different diffuser/nozzle elements is discussed. The variation of the diodes' performances at different applied pressures and different diffuser angles is outlined.

Keywords: MEMS, microvalves, microdiodes, simulation, CFD.

1. Introduction

Microelectromechanical systems (MEMS) are the subject of growing research activities in many fields of work. These small sensors and actuators, manufactured with lithography similar to those used for integrated circuitry, can be found in industrial and medical tools such as pressure sensors, micro valves and micro pumps [1]. The fields of application are: in automotive industry e.g. air bag sensor, in aerospace industry e.g. flow control around the wings of aircraft, in medical applications e.g. implanted drug delivery system, micro surgery and in chemistry e.g. liquid chromatography [2].

While the mechanical properties of micro devices are reasonably well studied, the fluid effects are still not well investigated. When gases and liquids are used in micro systems, the study of such flows sets problems due to the micron scale [3, 4]: For gases

- Flow properties in micro channels (continuum or molecular based flow model)
- Low Reynolds numbers at high speeds close to the velocity of sound
- Validity of non-slip condition at the solid-fluid interface

for liquids

- Introduction of apparent viscosity,

- Flow perturbation due to the gas bubbles,
- Bulk flow can be affected by electrostatic charges on the surface, surface effects,

and for both

- Importance of thermal exchanges,
- Method of measurement of the physical properties.

Micromechanics is a multidisciplinary research field, which is still being investigated. As the systems become more and more complex, there is an increasing demand for both theoretical and experimental work on physical phenomena and also on simulation tools. Generally, experiments require great efforts and are usually very expensive, therefore computational fluid dynamics can be an attractive method in micro-engineering [5]. But in the great majority of cases we do not know if CFD can predict MEMS behaviour and so more experimental data are necessary. Nevertheless, some previous experimental results show that CFD can help in the definition of the geometry of microfluidic devices. So in this paper we present CFD results for liquids in the case of laminar flows inside microdiodes. We obtained some interesting results on the behaviours which can help in pumping system design. Of course they must be validated later by experiments.

2. Validation of our Numerical Simulation

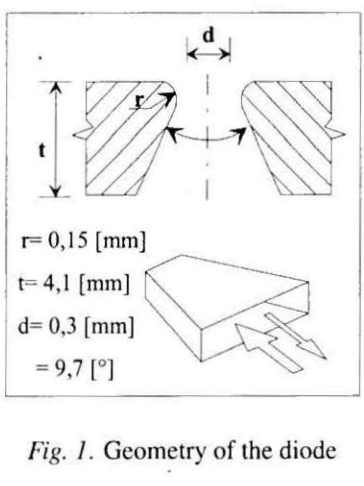

Fig. 1. Geometry of the diode

Pumps with check valves have many drawbacks such as the risk of reduction in performance and reliability due to wear and fatigue. To avoid these problems it is possible to use diodes instead of valves. The principle of the newly designed pump is based on the fact that the fluid diodes can be geometrically designed to have a lower volume flow in one direction than in the other for a given pressure drop. According to the membrane displacement of a micro pump the diodes act in opposite directions and during one pump cycle a net flow rate can be obtained. Therefore, to increase the pump performance, that of the diodes' has to be optimised [6, 7].

For the validation of our numerical simulation the published numerical and experimental results of Anders OLSSON et al. [8] are used. The geometry of the tested element is shown in *Fig. 1*. The entry of the diffuser has a rectangular cross section.

To obtain a better convergence, the initial velocity condition was set close to the measured values calculated from the experimental flow rate in the inlet cross section. In this study, unsteady simulation has been used. During the simulations, the non-slip boundary condition was maintained, other numerical parameters are reported in the *Table 1*.

Table 1. Simulation parameters

Mesh	Physical model	Numerical methods
Hexahedral	Laminar Unsteady Incompressible Fluid viscous 3D	Pressure: first order Moment: first order SIMPLE

In *Fig. 2.a* and *Fig. 2.b* the Olsson's experimental and numerical results are plotted with our simulation results. These ones show a much better agreement with Olsson's experimental results thus making this simulation approach possible for use in determining the fluid properties of such micro elements [6].

3. Flat Walled Diffuser/Nozzle Type Microdiodes Simulations

The geometry of the studied diffuser element is as described in *Fig. 1* but without rounded inlet, with $r = 0$, the length $t = 370$ μm and $d = 100$ μm. The diffuser is placed between two pipes the dimensions of which can be considered as infinite compared to the dimension of this device.

In this case, the entries of the diffuser have a sharp inlet because many micro pumps are made with this type of element as the literature study shows. The reason of this is that the fabrication procedure is easier to perform. We wanted to study the effect of the variation of the angle whilst maintaining all other dimensions, keeping in mind that the shape of the diffuser entry can have a great influence on the diode behaviour [9, 10]. The simulation parameters, in this case are reported in the *Table 2*.

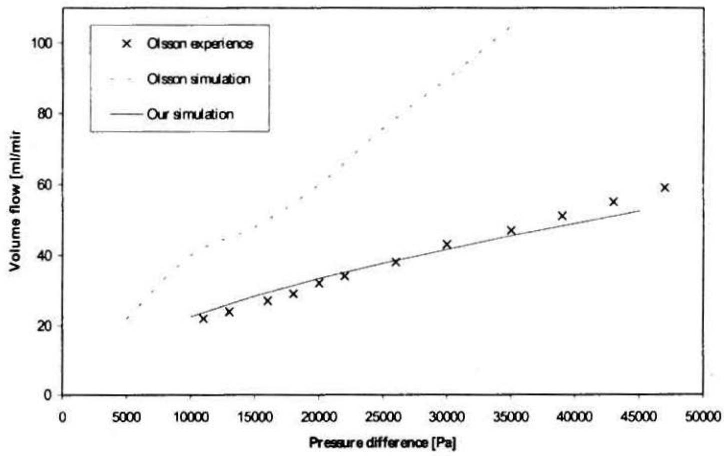

Fig. 2.a. Results at different pressure drops for diffuser direction

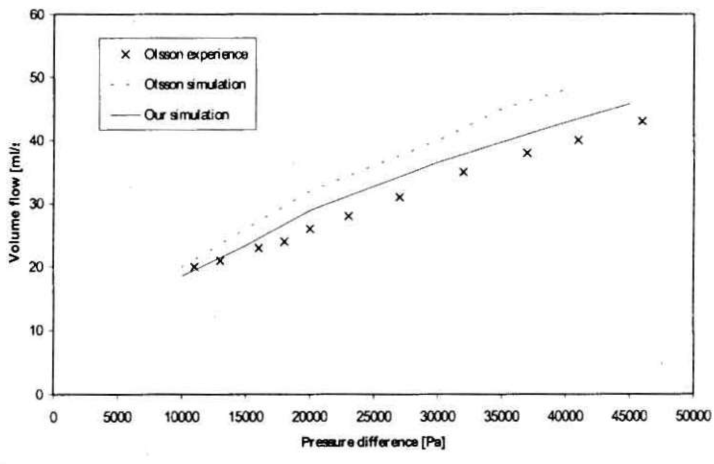

Fig. 2.b. Results at different pressure drops for nozzle direction

In *Fig. 3* the velocity fields (in m/s) are plotted for $\Delta P = 8000$ Pa and for different conical angles. In general, the losses are determined by three terms: the sudden contraction, sudden expansion and gradual losses. Entrance and gradual losses are highly dependent on entrance geometry but exit losses are less. Because of the sudden sharp contraction the flow separates from the wall in all cases but the more the conical angles (α) are important, the more the boundary layers of the returning flow are important in the diffuser.

The formation of this recirculation zone is the cause of the increasing losses in the diffuser direction when the angle α is growing. On the other hand, the boundary

Table 2. Simulation parameters

Mesh	Physical model	Numerical methods
Hexahedral	Laminar Steady Incompressible Fluid viscous 3D	Pressure: second order Moment: second order SIMPLE

layer does not change significantly in the nozzle direction when α is growing. To evaluate the operation of various types of diodes we have introduced the concept of back to front volume flow ratio or diode efficiency:

$$D = \frac{Q_d}{Q_n}$$

where: Q_d – volume flow in diffuser direction
Q_n – volume flow in nozzle direction

It is known that this ratio depends on the pressure difference and angle α so we can define efficiency curves as $D_{(\alpha,p)}$. With this equation the efficiency is > 1 when losses are less in the diffuser direction than in the nozzle direction.

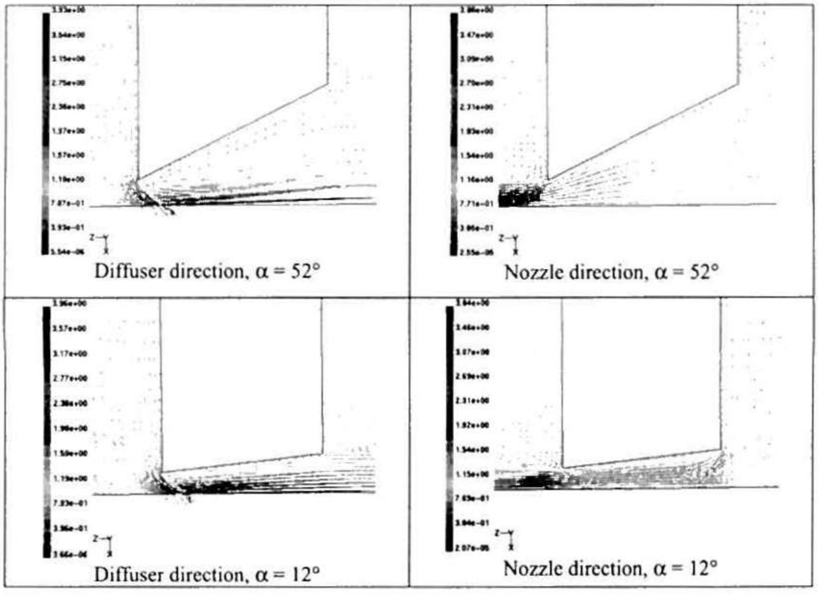

Fig. 3. Velocity field for different angles α

Simulations were performed for different conical angles and for different pressure drops (see *Fig. 4*). The results show that the behaviour of the diffuser depends strongly on the pressure difference and the geometry, namely on the angle α. As the pressure difference decreases between the inlet and outlet, and as the flow rate decreases, the positive direction of the diode is the diffuser direction even at high conical angle values. In the case of higher Re numbers, and when α is sufficiently high, as the diode becomes more resistant in the diffuser direction, due to the growing vortex formation, the positive direction is the nozzle direction. However, even at a relatively high velocity flow, the losses in the nozzle direction remain predominant if the conical angle is less than 20°. From these results two maximal efficiency zones can be defined, one in the nozzle direction (zone A) and the other in the diffuser direction (zone B).

It is important to note that for angles α within the maximal efficiency zone A (between 40° and 50°), the working direction changes for low pressure drops (less than 2000 [Pa]) which can be important for the design of the diodes.

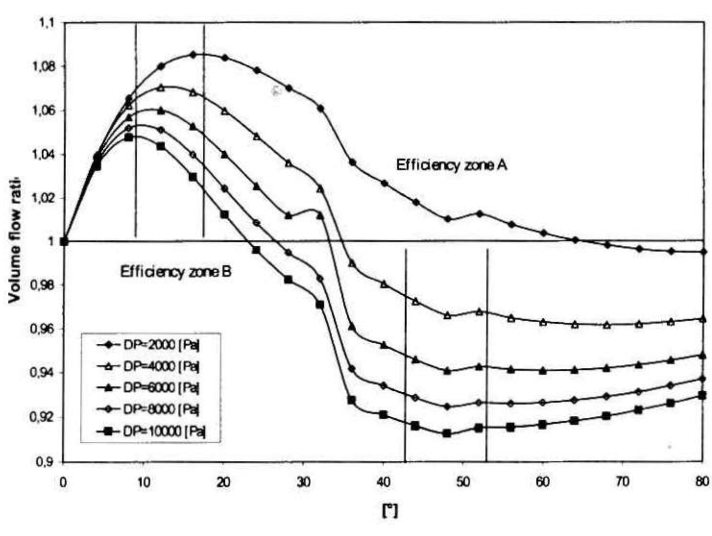

Fig. 4. Efficiency curves of flat walled diode (volume flow ratio)

4. Pyramid Diffuser/Nozzle Type Microdiodes Simulations

Finally, the pyramid type diffuser with the geometry shown in *Fig. 5* was tested. The simulation results are plotted in *Fig. 6*. The main difference between the flat walled and pyramid shaped elements is that for the latter, the transition zone becomes influential at $\alpha = 10°$. The maximal efficiency can increase more quickly than in the case of flat walled diodes and reach higher values for some pressure drops. A

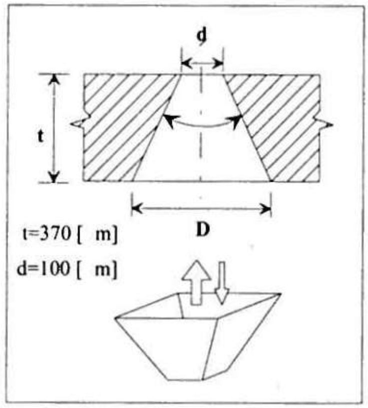

Fig. 5. Pyramid geometry

better efficiency in the nozzle direction can also be observed. Indeed at high pressure drops, the volume flow ratio is better for α about 40° in the nozzle direction than at low pressure drops for α about 5° in the diffuser direction. Moreover, unlike the flat walled diodes, in the maximal efficiency zone *A*, the working direction remains independent of the pressure drop allowing the use of the pyramid shaped diode in both directions according to the angle α chosen or imposed by the fabrication techniques.

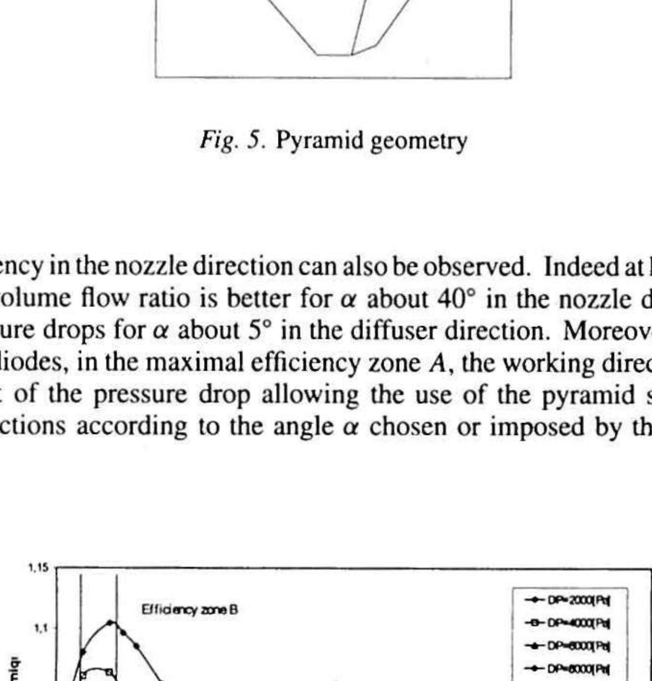

Fig. 6. Efficiency curves of pyramid type diode (volume flow ratio)

5. Conclusion and Perspectives

We have studied diffuser nozzle elements in micro scale and compared our simulations with experimental and numerical results of Olsson and good similarities were found.

Therefore we came to the conclusion that our numerical simulations can help in the understanding of flow properties in micro devices. Our results show that for the diode performance, the diffuser angle plays an important role independently of the diffuser entry shapes. Small changes in design parameters caused large changes in performance and could completely convert the diodicity effect. As it is shown in previous figures the pyramid shaped diffuser has a maximal efficiency in the diffuser direction for α around 8° and for α close to 15° for the flat walled one. This fact could be the outcome of the three dimensional vortex formation in the pyramid diode which increases the energy losses. Another difference between the pyramidal diode and the flat walled one is that the working direction of the latter can change around the maximal efficiency zone in the nozzle direction when the pressure drop decreases. These considerations can be very important for the design of micro pumps to maintain the volume flow in the desired direction.

Further investigations should permit to validate the simulated characteristics of the diodes studied in this paper. The influence of the entry shapes also has to be simulated in order to optimise the performances of these diodes. Such investigations should also be very useful for understanding of check microvalves behaviour studied in our team, [11].

References

[1] BÁLINT, G., Microsystems in Medical Applications; *Scientific Review of Clinical Techniques*, Budapest, March, 1997, pp. 63–68.

[2] Yellow Book Programme Information and Organisation; EURIMUS Submitted to Eureka; March 1998.

[3] COLIN, S. – AUBERT, C. – CAEN, R., Unsteady Gaseous Flows in Rectangular Microchannels: Frequency Response of One or Two Pneumatic Lines Connected in Series, *European Journal of Mechanics B/Fluids*, **17** N. 1 (1998), pp. 79–104.

[4] GRAVESEN, P. – BRANEBJERG, J. – JENSEN, O. S., Microfluidics – A Review, *J. Micromech. Microeng.*, **3** (1993), pp. 168–182.

[5] BÁLINT, G., Study of Microfluid Valves; Proceedings of μDevices'99 Workshop, Budapest, Hungary, 26–28 May 1999, pp. 7–15.

[6] OLSSON, A. – STEMME, G. – STEMME, E., A Valve-Less Planar Fluid Pump with two Pump hambers; Sensors and Actuators A 46–47, 1995, pp. 549–556.

[7] GERLACH, T., Pumping Gases by a Silicon Micro Pump with Dynamic Passive Valve; Transducesr'97; June 16–19 1997, pp. 357–360.

[8] OLSSON, A. – STEMME, G. – STEMME, E., Simulation Studies of Diffuser and Nozzle Elements for Valve-less Micropumps, *Int. Conf. On Solid State Sensors and Actuators Chicago*, June 1997, pp. 1039–1042.

[9] JIANG, X. N. – ZHOU, Z. Y. – LI, Y. – YANG, Y. – HUANG, X. Y. – LIU, C. Y., Experiments and Analysis for Micro-Nozzle/Diffuser Flow and Micro Valveless Pumps. Int. Conf. On Solid State Sensors and Actuators Chicago, June 1997, pp. 369–372.

[10] STEMME, E. – STEMME G., A Valveless Diffuser/Nozzle-based Fluid Pump, *Sensors and Actuators* A 39, 1993, pp. 159–167.

[11] ANDUZE, M., Experimental and Numerical study of Liquid Flows in Fluidic Microsystems; Thesis, Toulouse, January 2000.