Pressure driven robust micro pump

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ABSTRACT

For several applications such as small-scale bioreactors there is a lack of suitable commercially available micro pumps. Absolute requirements would be very small flow rates, small size and tolerance of bubbles. Therefore we developed a membrane-type micro pump of modular design. We have developed two different systems: One consists of two check valves and a pumping membrane. The other is a peristaltic pump consisting of a fluidic channel chip, a PDMS-membrane and a cap chip with a spring. Both systems can be integrated into different housings e. g. for several biological applications. The dimensions without housing are only 5 x 5 x 1 mm³ and – depending on the frequency and actuation pressure – we can generate a pump rate up to 1000µl/min. Since the pump can deliver both, gas and liquids, it is absolutely bubble-tolerant. This is of advantage, especially for applications where gas bubbles cannot completely be avoided.

Keywords: micro pump, diaphragm pump, bubble tolerance, PDMS, micro valve

1 DESIGN

1.1 Introduction

The construction of a new micro pump was motivated by the fact that no commercial pump available met the requirements of our application. The pump should be able to address each well of a multi well plate separately. This means ideally every well being equipped with its own pump. Therefore size and connection points of the micro pump are given by the layout of the multi well plate and we designed a pumping chip of 5 x 5 mm² size. Further, for our application the pump must be able to deliver liquids as well as gases at flow rates of up to 400 µl/ min and it should work at back pressures of up to 20 kPa.

Based on these requirements we chose to develop a membrane-type pump. The fundamentals of bubble tolerant micro pumps are described in [1]. Due to the small size of our pump we also have a small diaphragm. In order to make the pump bubble tolerant we need a large stroke of the membrane. Since this cannot be generated by a piezo bimorph – due to physical limits – we have decided to actuate the pump by compressed air. Actuation by compressed air has the additional advantage of promoting diffusion (gas exchange) between compressed air and the medium to be pumped, thereby allowing aeration, oxygenation etc.

1.2 Pressure source

For actuation of our pump we need a source that can generate compressed air or vacuum. Hence we built a device with an external pressure intake. This device can generate pressure square pulses with defined frequencies from 0.1 to 99.9 Hz. Over pressure and vacuum can be adjusted separately by pressure regulators.

1.3 Housing

For using the pump in a labaratory, we need macroscopic connection points. In most cases suitable connectors are Luer connectors. For an easy exchange of the pumping device this is only clamped in the casing. Fig. 1 shows a complete pump with inlet, outlet pipe and the feeding pipe. With another cap this assembly could be used for testing valves. The body could also have some internal fluidic circuits instead of external connections.

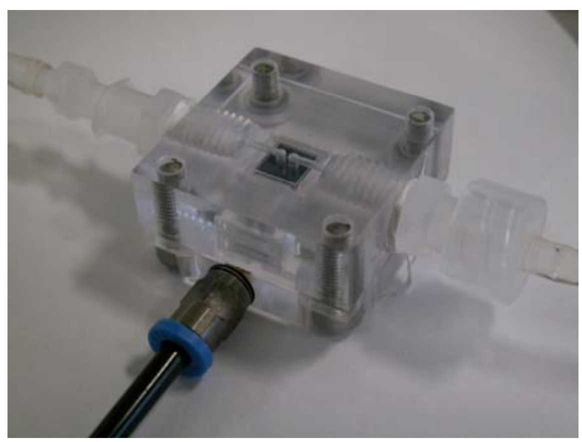

Fig. 1 Micro pump with housing

1.4 Membrane pump with check valves

The micro pump is subdivided into a valve chip, a diaphragm, a sealing and a housing. Fig. 2 shows the valve chip with a membrane on top. The material of the membrane and sealing is PDMS (Sylgard 184).

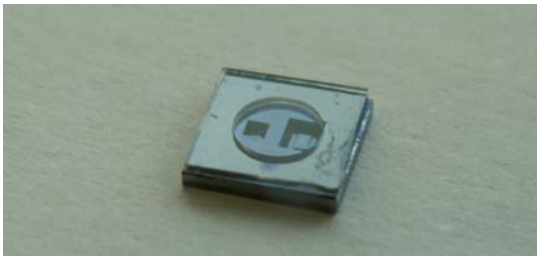

Fig. 2 Valve chip with membrane

1.4.1. Simulation of the valve

In order to find a valve with small pressure drop in flow-through direction and a tiny backflow we simulated the behavior of the valve with CFD-ACE+ (ESI-Software). This is a CFD (Computational Fluid Dynamics) program. Fig. 3 shows a simulated valve in flow-through direction with the inlet being pressurized with 10kPa.

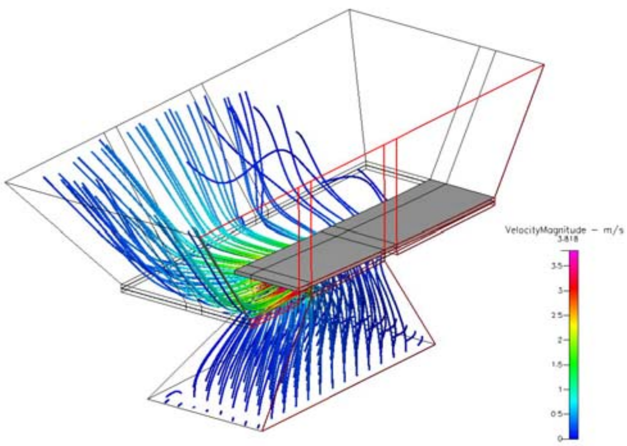

Fig. 3 Micro check valve with streamlines

The simulation showed that thickness of the flap valve should be approx. 10µm and the opening should have a size of 300 x 300 µm². Other valve parameters are defined by the design of the housing (e.g. limitations of size).

1.4.2. Fabrication of the valve chip

The valve chip is produced with micro technologies: The material used is silicon which was masked by microlithography. The wafer was etched in potassium hydroxide and then the valve flaps were etched with a reactive ion etching process. Finally two identical wafers were bonded with a silicon fusion bonding process.

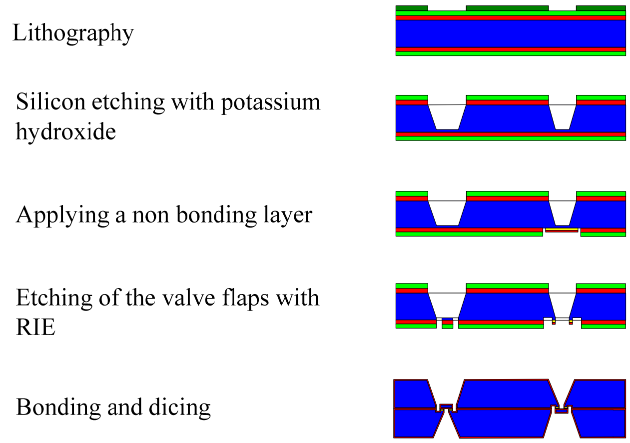

Fig. 4 Fundamental process steps

Although from the technological view it is a problem to create regions of non bonding areas (fig. 4), these were necessary to get a flap valve that can be opened. There are two ways to solve this problem: First, the valve seat can be dimensioned very small (few microns) [2] and second, you can create a layer inhibiting the bonding. We choose the second way, because of a better sealing with a wider valve seat compared to a smaller one. Our experiments show, that the bonding can be inhibited with a thin poly-silicon layer.

1.5 Peristaltic micro pump

Such as the membrane pump also the peristaltic pump is actuated by pneumatics but the working principle is different. In case of the peristaltic pump the function of the valve is integrated into the diaphragm. The deflection membrane opens and closes the inlet and outlet of the pump. An advantage of this pump is that we can control the pumping direction by changing the actuation frequency.

2 RESULTS AND DISCUSSION

2.1 Membrane pump with check valves

First we have characterized the valves. Fig 5 shows a selection of valves. Valve 3 and valve 4 belong to the same pumping chip (inlet and outlet) while valve 1 and valve 2 belong to different pumping chips. Valve 3 and 4 would ideally have identical characteristics. The discrepancies shown in fig. 5 can be explained be tolerances of wafer thickness and etch rates, which result in slightly different characteristics.

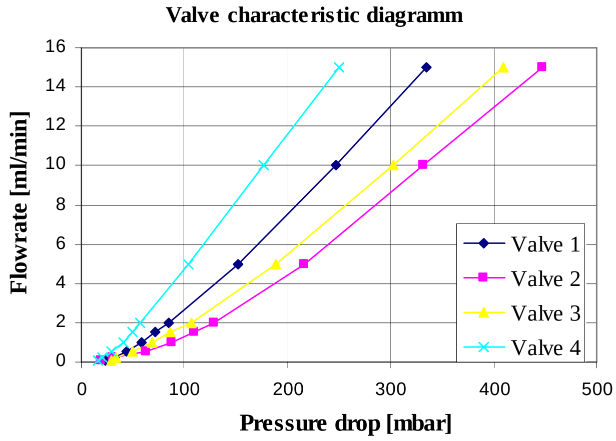

Fig. 5 Valve characteristics

The next test characterizes the flow rate of the pump. In the following diagram (fig. 6) flow rate vs. actuation frequency is shown. The feeding pressure in this case is +20 kPa and -20 kPa respective the atmospheric pressure and water was used as pumping medium. With air as pumping fluid we would get similar characteristics.

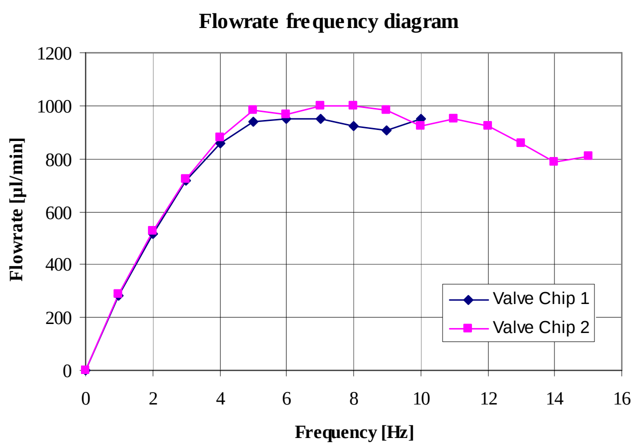

Fig. 6 Flowrate at +20 kPa and -20 kPa actuation pressure

For applications where lower flow rates are needed these can be achieved by decreasing the actuation pressure. Fig. 7 shows the flow rates using different valve chips at an actuation pressure of +15 kPa and -6 kPa.

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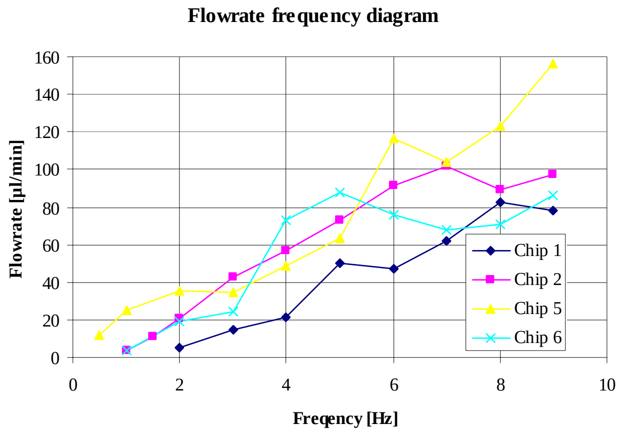

Fig. 7 Flowrate at +15 kPa and -6 kPa actuation pressure

Our goal is to develop a micro pump which can work reliably for several days without any interruption. Although our pump shows very promising characteristics, concerning long-term stability there are still some points to optimize. The valve may get blocked by longer particles such as fuzz. Therefore one way of optimization might be using a filter at the inlet. Another way could be the use of a softer material like silicone as a flap valve.

The future work is directed towards an increase of reliability of the micro pump.

3 ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Richter, R. Linnemann, P. Woias: Robust design of gas and liquid micropumps, Sensors and Actuators A68, pp. 480-486, 1998

[2] R.Zengerle, M.Richter: Simulation of microfluid systems, Journal of Micromechanics and Microengineering, 1994

[3] D.C.S. Bien, S.J.N. Mitchell and H.S. Gamble, Fabrication and characterization of a micromachined passive valve, Journal of Micromechanics and Microengineering, 2003