ELECTROMAGNETICALLY ACTUATED BALL VALVE MICROPUMPS

C. Yamahata, F. Lacharme, J. Matter, S. Schnydrig, Y. Burri and M. A. M. Gijs
Institute of Microelectronics and Microsystems
Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland

Fluid delivery is important for Lab-On-a-Chip (LOC) applications and integration of micropumps in fluidic chips or cartridges is of major interest. We present two types of ball valve reciprocating micropumps for LOC applications; both are actuated with an external electromagnet (Fig. 1). A first type of disposable micropump is made out of polymethylmethacrylate (PMMA), while a second type of re-usable micropump is made out of borosilicate glass (Fig. 2); the latter has the advantage of being sterilisable at high temperature (120 °C). Both types of micropumps were realized using powder blasting micro-erosion [1,2]. The flexible magnetic actuation membranes were fabricated in polydimethylsiloxane (PDMS) with embedded NdFeB magnetic powder for the plastic micropump, and with a cylindrical NdFeB magnet for the glass micropump (Fig. 3).

Most developed micropumps were Si-based with piezoelectric actuation, limiting membrane deflection and stroke volume. Only few papers report on the use of ball valves, despite their high directional efficiency [3-5]. With the development of LOC applications, plastics and glass have become the preferred material for their cost-effectiveness and chemical inertness, respectively. Major advantages of our micropumps are (i) the large stroke of the soft membrane, resulting from the electromagnetic actuation, which makes the micropumps self-priming, and (ii) the high directional efficiency of the flow due to the use of the ball valves, giving rise to a pumping backpressure of up to 280 mbar.

1.0 mm and 0.7 mm diameter stainless steel balls were integrated in the layered PMMA and glass structures, respectively. The NdFeB isotropic powder for the polymer-bonded magnet has a remnant induction $B_r \sim 0.75$ T, a theoretical density of 7.43 g/cm^3 and an apparent density of 4.2 g/cm^3. From the experimental density curve of the magnet (Fig. 4a), we found that the optimum powder volume fraction is 60 % [6]. However, the high-density samples are inhomogeneous due to a lack of binder, as shown in Fig. 4b. Therefore, optimized homogenous polymer bonded magnets could be fabricated using up to 50 % vol. powder.

Actuation was done with an external electromagnet consisting of a 4800 turns coil and a soft iron core. Fig. 5 reports the electromagnetic forces obtained with 0, 50 and 100 mA continuous currents for the two types of magnets. Without a current, there is an attractive force between the magnet and the soft iron core, while application of a current allows to generate repulsive forces of up to 0.5 N. These force measurements are related to the maximum backpressures achieved using sinusoidal current of varying frequency (Fig. 6). A maximum backpressure of 225 and 280 mbar was obtained with the PMMA and glass micropump, respectively. Water has been successfully pumped at flow rates of up to about 5.5 mL/min with the two types of pumps (Fig. 7).

The frequency-dependent water flow rate characteristics are similar to the characteristics of an electrical RLC model. Table 1 shows the equivalence between the electrical model and the fluidic model in terms of various parameters of the flow system (V : pumped volume, r : fluid density, h : dynamic viscosity, l : microfluidic channel length, A : channel cross section, D_H : hydraulic channel diameter) [7]. Fig. 8 shows that the resonance frequency (20–30 Hz) and the frequency-dependence of the flow rate can be very well explained (without any free fitting parameter) with our second order fluidic damped oscillator model.

Corresponding author: Christophe Yamahata, Institute of Microelectronics and Microsystems, Swiss Federal Institute of Technology Lausanne (EPFL), Building BM 3132, CH-1015 Lausanne, Switzerland; Tel: +41 21 693 66 39; Fax: +41 21 693 59 50; E-mail: Christophe.Yamahata@epfl.ch

References:

[1] C. Yamahata, M. A. M. Gijs, *proc. IEEE 17th MEMS conf.*, pp. 458-461, 2004.
[2] D. Solignac et al., *Sens. Actuators A* **92** (1-3), pp. 388-393, 2001.
[3] M. C. Carrozza, N. Croce, B. Magnani, P. Dario, *J. Micromech. Microeng.* **5** (2), pp.177-179, 1995.
[4] O. Krusemark, A. Feustel, J. Müller, *proc. microTAS '98 conf.*, pp. 399-402, 1998.
[5] A. Sin, C. F. Reardon, M. L. Shuler, *Biotech. and Bioeng.* **85** (3), pp. 359-363, 2004.
[6] F. Weber, P. Scheibner, Ph.D. thesis, *Technischen Universität Chemnitz-Zwickau*, 1994.
[7] T. Bourouina, J.-P. Grandchamp, *J. Micromech.Microeng.* **6**, pp. 398-404, 1996.

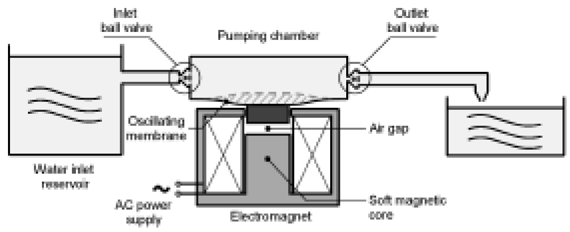

Fig. 1 : Schematic diagram of the electromagnetically actuated ball valve micropump.

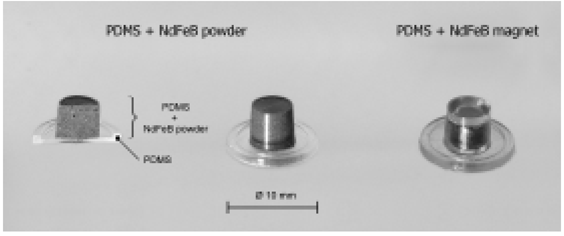

Fig. 3 : Silicone polymer membrane with integrated magnet. The left photograph shows a cut view of the PDMS membrane fabricated with NdFeB powder (central photograph). The volumic density of powder is 40 %. The right photograph shows a PDMS membrane with embedded rare-earth magnet.

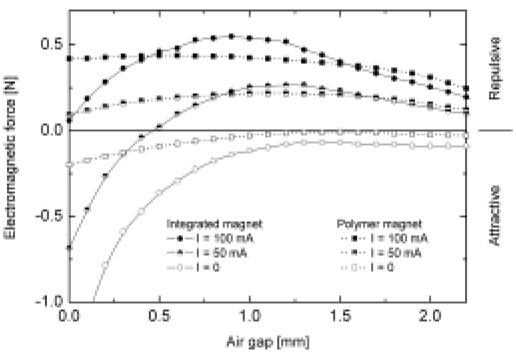

Fig. 5 : Dependence of the force generated by the electromagnet with the position of the permanent magnet with respect to the soft magnetic core of the electromagnet (see Fig. 1). The measurements are done for 0, 50 mA and 100 mA continuous current.

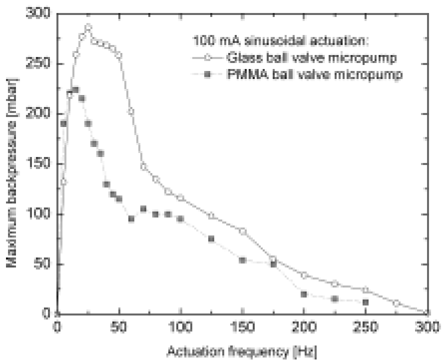

Fig. 6 : Comparison of the backpressure – frequency characteristics of the two types of micropumps. The pumps were actuated with an external electromagnet excited with a 100 mA sinusoidal current.

Electric	Fluidic
Voltage U	Pressure P
Current I	Flow rate $\phi = \frac{dV}{dt}$
Resistance R	Fluid resistor $R = \frac{128\eta l}{\pi D_H^{\ 4}}$
Capacitance C	Fluid capacitor (soft membrane) $C = \frac{dV}{dP}$
Inductance L	Fluid inductor $L = \frac{\rho l}{A}$
Diode	Valve

Table 1 : Equivalence between the fluidic and the electrical model.

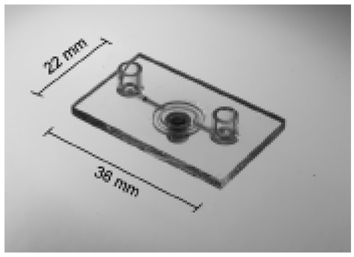

Fig. 2 : Ball valve micropump fabricated out of borosilicate glass. External dimensions : 36 mm × 22 mm.

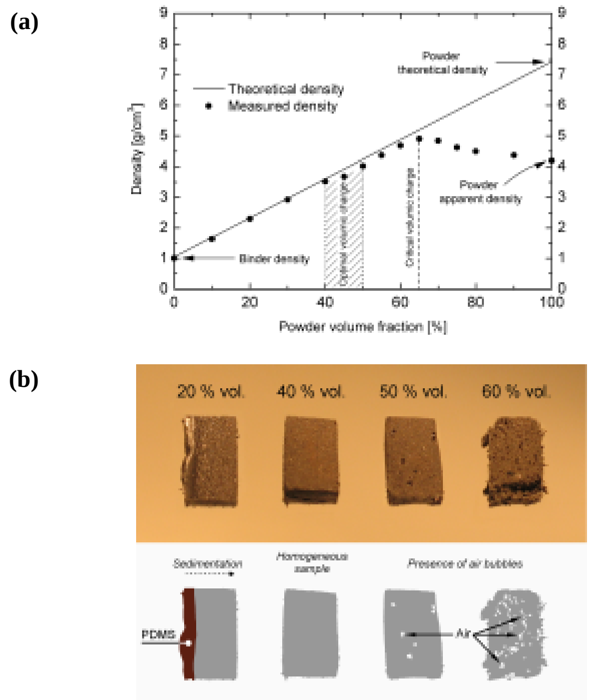

Fig. 4 : (a) Relation between the powder volume fraction and the density of the magnet. (b) Test of the homogeneity of the NdFeB powder bound in a PDMS polymer matrix. The optimum volume fraction is obtained for 40 – 50 % of powder.

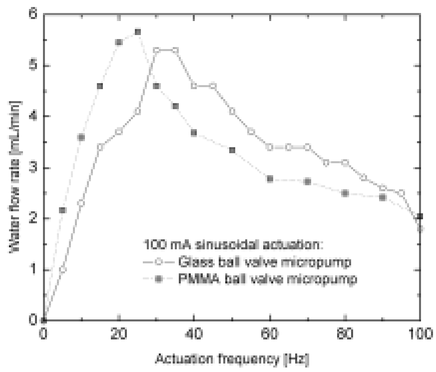

Fig. 7 : Comparison of the water flow rate – frequency characteristics of the two micropumps. The pumps were actuated with an external electromagnet excited with a 100 mA sinusoidal current.

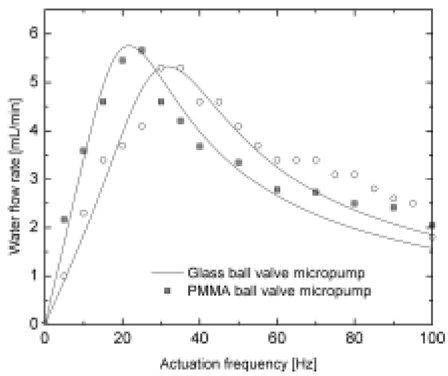

Fig. 8 : Second order fit of the water flow rate curves from Fig. 7 using the fluidic damped oscillator model.