

# A Ferrofluid Micropump for Lab-on-a-chip Applications

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**Summary:** A disposable micropump is presented that uses the piston actuation principle and relies on the magnetic properties of a ferrofluid, a colloidal suspension of nanosize ferromagnetic particles. The cost effective micropump consists of 7 bonded layers of polymethylmetacrylate (PMMA) that are either micromachined or structured by powder blasting. Two silicone check-valves are also integrated in the microchip. External dimensions of our prototype are 36 mm x 22 mm x 5 mm. The magnetic liquid plug is externally actuated by a motorized permanent magnet. Water has been successfully pumped at a flow rate of 30  $\mu\text{L}/\text{min}$  without backpressure; pumping is demonstrated up to a backpressure of 25 mbar.

**Keywords:** Micropump; Ferrofluid; Powder blasting; Check-valve; PMMA; Lab-on-a-chip.

**Category:** 7 (Fluidic devices)

## 1 Introduction

Advances in microfluidic MEMS technology and the interest of biochemical companies for integrated analytical systems have led to the Lab-on-a-chip (LOC) concept. The cost-effective transport of small quantities of biochemical fluidic samples, in the range of few microliters per minute, remains an important challenge for these devices. Most of the micropumps developed to date were silicon based and piezoelectrically actuated [1,2]. However, such kind of micropump remains expensive and is therefore not suitable for LOC disposable devices. Integration of micropumps in disposable chips requires the development of other microfabrication technologies and actuation methods to lower the costs.

The use of magnetic liquids is an innovative actuation method for fluid handling, since ferrofluids have shown their great potential in piston pumping [3]. Pérez-Castillejos [4,5] et al. reported different possibilities of the use of ferrofluids for microfluidic applications. Menz [6] and Wagner [7] et al. presented microfluidic systems containing ferrofluids displaced with integrated mobile magnets. Greiwell [8] realized an electromagnetically actuated ferrofluid micropipette. Hatch [9] and Kamholz [10] et al. realized a ferrofluid micropump where the ferrofluid plugs serve both for pumping and valving.

In the mean time, the development of plastic micropumps [11,12] has become particularly attractive for disposable devices. In this study, a polymethylmetacrylate (PMMA) microfabrication technique for the realization of miniaturized plastic pumps using a ferrofluid pumping mechanism is presented. The prototype consists of two check-valves separated with a large channel that is filled with a ferrofluid plug. The external magnetic

actuation setup avoids the integration of expensive elements in the micropump, which is essential for implementation of a disposable cartridge.

## 2 Microfabrication of the micropump

Complex parts are realized with precision milling tools, while channels and other planar structures are realized using the powder blasting technique. This rapid prototyping method offers an efficient solution for the fabrication of fluidic devices, with minimum channel dimensions down to 100 micrometer.

In a first step, a metallic mask resistant to powder blasting is realized by a CO<sub>2</sub> laser. Using this mask, fluidic structures are realized in 250 micrometer thick PMMA sheets. The different layers are assembled into a monolithic three-dimensional microfluidic structure by an appropriate chemical binding step. The assembly step is realized in a hot press and only takes a few minutes. Silicone membranes with an external diameter of 7 mm also are integrated into the chip. A thin layer of PMMA, microstructured by powder blasting, and a burst view of the integrated check-valve are shown in Fig. 1.

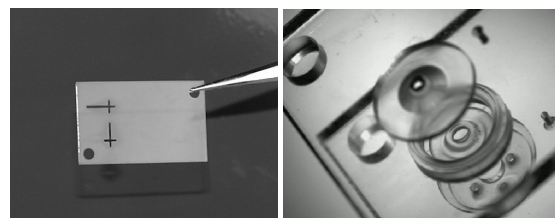


Fig. 1. Left: Photograph of a PMMA sheet structured by powder blasting technology (36 mm x 22 mm x 250  $\mu\text{m}$ ). Right: Burst view of a check-valve showing the corrugated silicone membrane ( $\text{\O}7$  mm) between two micromachined PMMA plates.

The integration of silicone valves in a microfluidic chip has enabled the development of a simple ferrofluid micropump. Our prototype is constituted of 2 silicone check-valves and 7 PMMA layers. A three-dimensional burst view of the prototype is represented in Fig. 2.

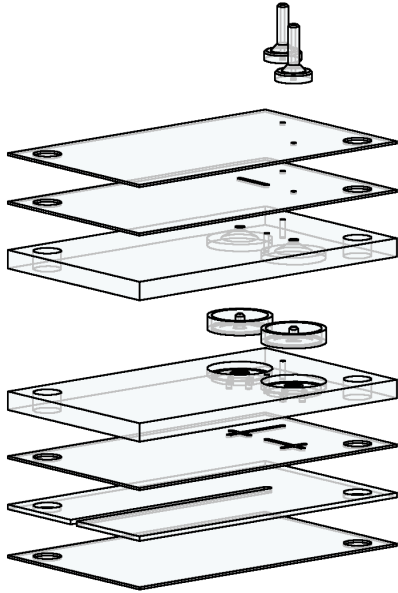


Fig. 2. Burst view of the micropump constituted of 7 PMMA layers and 2 silicone check-valves.

The micropump is based on the principle of piston reciprocating mechanism and the ferrofluid plug – which is moved in a 1 mm<sup>2</sup> channel – plays the role of the piston. A photograph of the realized prototype is shown in Fig. 3. Its external dimensions are 36 mm x 22 mm x 5 mm.

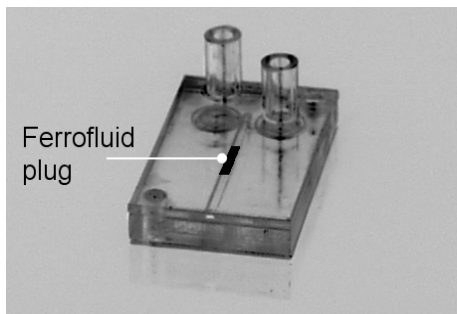


Fig. 3. Photograph of the ferrofluid micropump. External dimensions: 36 mm x 22 mm x 5 mm.

### 3 Performance of the micropump

#### 3.1 Check-valve characterization

A corrugated silicone membrane is taken from a commercially available check-valve. The performance of the integrated check-valve is tested on a dedicated chip before being integrated into the ferrofluid micropump.

As shown in Fig. 4, our assembled valve shows comparable characteristics with the original one and has the characteristic of a fluidic diode with an opening pressure of about 10 mbar.

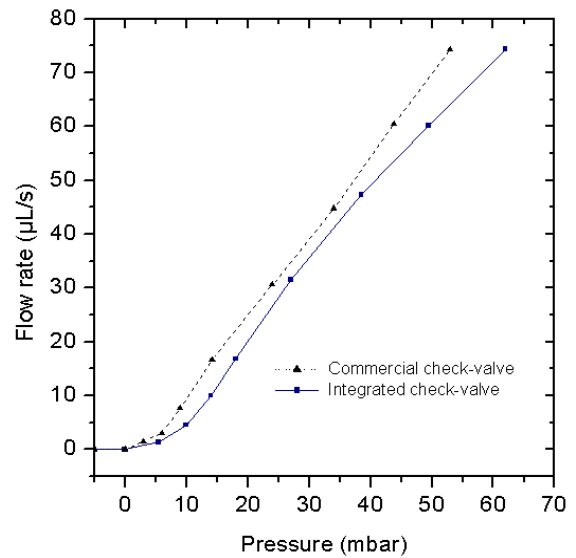


Fig. 4. Integrated check-valve characteristics compared to the commercial component.

#### 3.2 Ferrofluid characterization

The water based ferrofluid used in the experiments is synthesized in-house at EPFL. A Quantum Design MPMS2 SQUID magnetometer is used for magnetic characterization of liquid samples at 300 K. Measurements are reported in Fig. 5. The magnetic saturation of the ferrofluid is found to be 30 mT at this temperature, which will permit larger magnetic actuation forces than obtainable with most commercial ferrofluids.

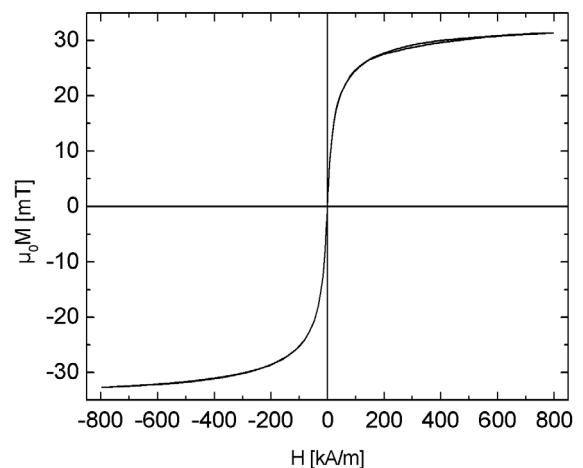


Fig. 5. Hysteresis loop of the sample when submitted to a magnetic field cycling between 800 and -800 kA/m.

### 3.3 Ferrofluid pump characterization

Water is pumped using a motorized rare-earth magnet that is displaced linearly at different speeds above the ferrofluid piston channel. A cylindrical NdFeB magnet (  $\text{\O}10\text{ mm} \times 4\text{ mm}$  ) is used in the experiments. The maximum pressure that the ferrofluid plug can withstand is measured to be 40 mbar, which is higher than the opening pressure of the valve.

Measurements are done with a capillary subjected to different hydrostatic counter pressures, in order to measure the effect of a backpressure. The pressure-flow characteristics are reported on Fig. 6. The maximum flow rate measured is about 30 microliters per minute, and a maximum backpressure close to 25 millibars is achieved with our ferrofluid. The maximum achieved backpressure corresponds well to the pressure generated with the ferrofluid minus the opening pressure of the valve. These pumping characteristics are of the best obtained with ferrofluid actuation [8,9].

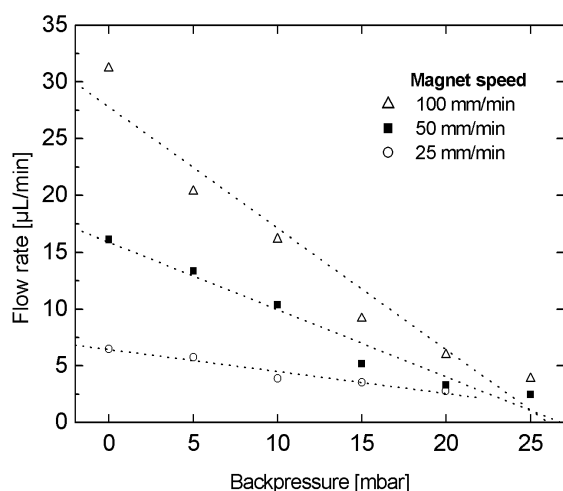


Fig. 6. Pressure-flow characteristics of water for different speeds of the rare-earth magnet.

### 4 Conclusion

We have presented a simple and low-cost prototyping method for microfluidic chips. It has been exploited to realize a plastic micropump based on the actuation of an in-house synthesized ferrofluid. The ferrofluid micropump has shown interesting characteristics, opening interesting possibilities for LOC applications.

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