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AN INTEGRATED MAGNETOFLUIDIC DEVICE ENABLING NOVEL ACUTATION FUNCTIONALITIES

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ABSTRACT

We report a simple solution for implementing a new set of reconfigurable magnetophoretic functions in a highly integrated hybrid magnetofluidic device. Using a dry film lamination technique, we designed and built a device enabling magnetic actuation of superparamagnetic beads at cell resolution, with attraction and repulsion possibilities, for essential functions such as focusing and trapping.

KEYWORDS: Magnetic actuation, Magnetofluidic, Micro-coils, Focusing

INTRODUCTION

Magnetic hybrid systems include external permanent magnets for the generation of a high and homogenous magnetic field, and integrated micro-coils locally producing a high gradient. Thinking about all the design possibilities those systems can offer is quite intriguing, and depending on the strength of the homogeneous magnetic field, we can either control single beads, or play with chains and clusters [1].

Our interest resides in controlling single cells and particles with high precision, and our work on planar coils [2] paved the way regarding the fabrication process and bulk separation functions. Hybrid devices seemed like a promising choice to deal with magnetic actuation at micro scale, that we achieved with two different focusing systems, a shift register and a trapping array.

EXPERIMENTAL

Microfabrication technology consists in a simple two-step process. Glass substrates (500 μm , Schott AF32) were chosen for imaging purposes during experiments.

The micro coils are wires of 5 μm width and height, and were obtained with standard micro-technology processes (Ti/Au metallization and electro-plating of copper or gold), then encapsulated with SU8 (10 μm) for protection. For the microfluidic channels, two layers of low cost dry film photoresist (20 μm , DF-1020, EMS Inc, Ohio) were laminated on top of the micro-coils, and structured with photolithography according to a technique we developed (3D structures can be achieved if piling more layers) [3].

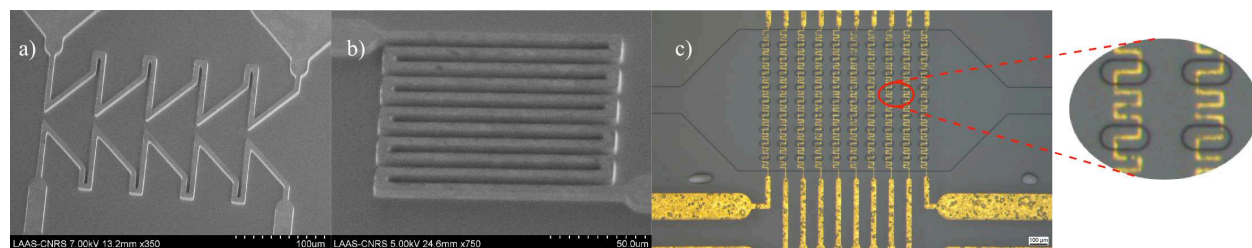


Figure 1: a) b) SEM images of microfabricated focusing and shift register units, respectively. c) Optical microscope picture of a cell trapping array (with coils and microfluidic channel). Cells or beads can be trapped on the coils between the pillars.

The permanent magnetic field value in the working zone is tuned by the distance between two permanent magnets (NdFeB, 1.3 T remanence) and the chip, from 40 to 70 mT with this setup. In order to control this distance, we built a chip holder (Fig. 2) that also comprises electrical and fluidic connection features (with a spring loaded connector and a manifold). The experimental setup is based on a fluorescence microscope (with an EMCCD camera), a pressure controller, and we developed an electronic board based on an Arduino/Labview solution to power the coils with positive or negative currents.

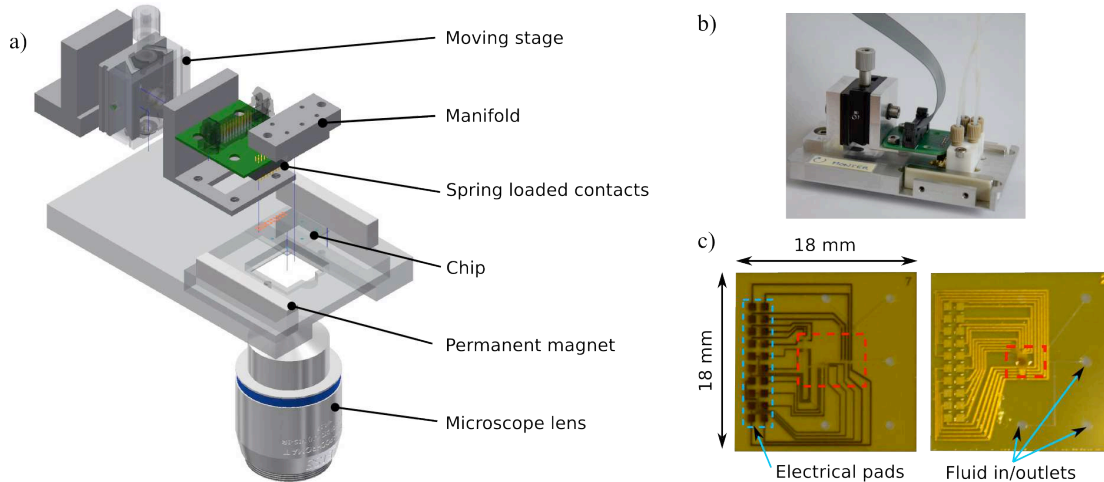


Figure 2: a) CAD drawing of the chip holder setup. Chosen materials were aluminum and PTFE (for the manifold). b) Actual built setup (connected), with mounted magnets and chip. c) Pictures of magneto-fluidic chips. Coils are made of copper (left) and gold (right). The red dashed lines represent the magnetic working zone (external field considered to be homogeneous).

Solutions of superparamagnetic beads were flowed through the system while recording the motion and trajectories of the beads for a given electrical current. We used $4.5 \mu\text{m}$ and fluorescent $8 \mu\text{m}$ diameter beads from Invitrogen and Spherotech respectively.

RESULTS AND DISCUSSION

Focusing $4.5 \mu\text{m}$ magnetic beads was achieved with two different designs (Fig. 3). Working in a stronger permanent field, we even showed deviation on a small chains of 2-3 beads. Beads velocity in Fig. 3 a) is $560 \mu\text{m/s}$, and we observed the same range of deviation at higher velocities (up to 2 mm/s), for a 85 mA current.

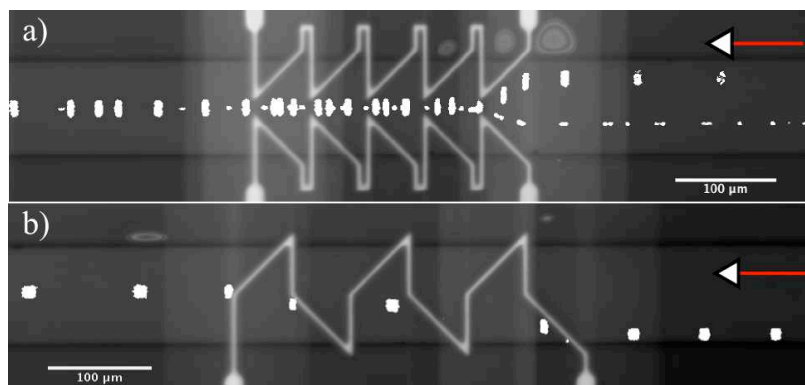


Figure 3: a) Two coils focusing device performing a deflection on two single beads (bottom) and a chain of 4 beads (top). b) Single coil focusing system centering a single bead. For both images, the electrical current was 85 mA . Red/white arrows point in the direction of the flow.

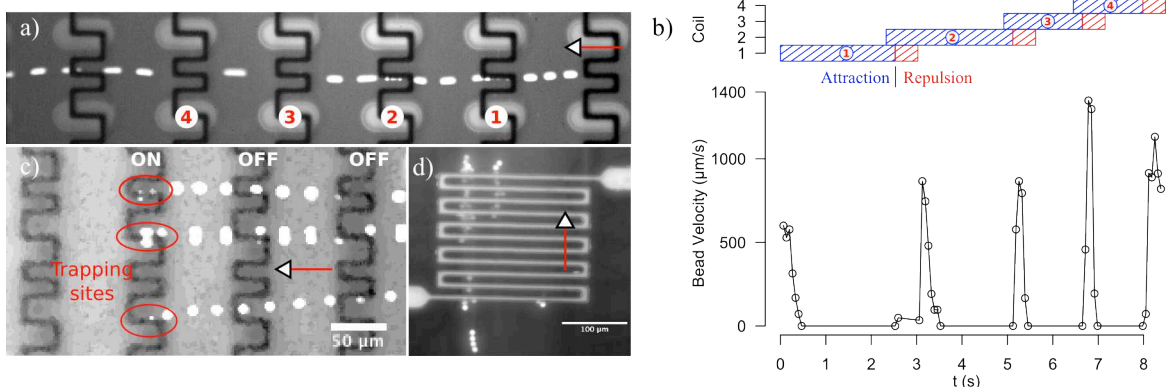


Figure 4: a) Trajectory of a $8\ \mu\text{m}$ diameter bead being captured and released 4 times with a trapping array. b) Coils actuation and bead velocity for experiment shown in a). c) Trapping of several beads simultaneously (trajectories shown). d) Possibility for the shift register to stop and trap beads and clusters. Red/white arrows point in the direction of the flow. Current of $100\ \text{mA}$ was used for all these experiments.

Magnetic traps are based on the attraction of a middle wire and repulsion (or focusing) of side wires; to release the particle quickly we invert the current polarity for a short amount of time. We demonstrated single bead trapping with $8\ \mu\text{m}$ diameter fluorescent beads (Fig. 4) at velocities above $1\ \text{mm/s}$, as well as trapping (and release) of bigger objects on the same chip (shift register). We therefore proved that cell arrays can be organized dynamically and reversibly.

CONCLUSION

Albeit this study only shows a few design possibilities of magnetic hybrid systems, our results show we are able to achieve key operations like trapping and focusing single magnetic beads (and small chains) at cell resolution. Dynamic cell trapping arrays find applications in co-culture and screening systems, as we intend to design and test new functions as tools for single cell biology experiments. Further developments are needed to explore beads concentration regulation (e.g., with a shift register) or automated capture and sorting of single cells coupled to analysis systems, but this would be the early stage of highly integrated complex magnetofluidic systems.

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