A NOVEL MAGNETIC CHAOTIC MIXER FOR IN-FLOW MIXING OF MAGNETIC BEADS

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ABSTRACT

This paper presents a novel magnetic active mixer using magnetic microtips for active mixing of magnetic beads or biocells. Mixing is achieved by a combined rotational/vibrational force exerted on the magnetic beads as the magnetic microtips are sequentially excited to produce a rotating magnetic field. The developed active mixer can be easily integrated with microfluidic systems by using the magnetic interconnection technology.

KEYWORDS: ***Micro mixer, chaotic mixing, magnetic tips, magnetic beads***

INTRODUCTION

For cell analysis, the mixing of specific cells or subcellular bio-molecules is one of the most challenging tasks to obtain an appropriate reaction in a short period of time. Various mixers have been developed and reported including passive and active mixers [1-3]. In biological analysis, biocells are usually attached to magnetic beads for later magnetic force separation. In order to achieve uniform distribution of biocells on the magnetic beads, it is essential to mix them efficiently

In this paper, a novel magnetic chaotic mixer is developed for the purpose of mixing flows with and without magnetic beads. The micro-magnet mixer is fabricated using on-chip magnetic interconnection technology with through-hole vias. The interconnection technology isolates the electromagnets from the pole tips, which gives wide flexibility in microfluidic system design.

DESIGN AND SIMULATION

The micro mixer is driven by three magnetic pole pairs excited with electromagnets coupled to magnetic pole tips using through-hole vias as shown in Figure 1. The microfluidic channels are fabricated in close proximity of the pole tips. The driving electromagnets and the actuating tips are on opposite sides of the wafer reducing the interference between the exciting circuit and actuating structure. The use of external electromagnets simplifies the device fabrication, increases the magnetic force, and reduces undesirable heating of on-chip biofluids.

As shown in Figure 2, before excitation the beads are randomly distributed in the center junction region (Figure 2(a)). When a sequential driving signal is applied (Figure

7th International Conference on Miniaturized Chemical and Biochemical Analysis Systems
October 5–9, 2003, Squaw Valley, California USA

0-9743611-0-0/µTAS2003/$15.00©2003TRF

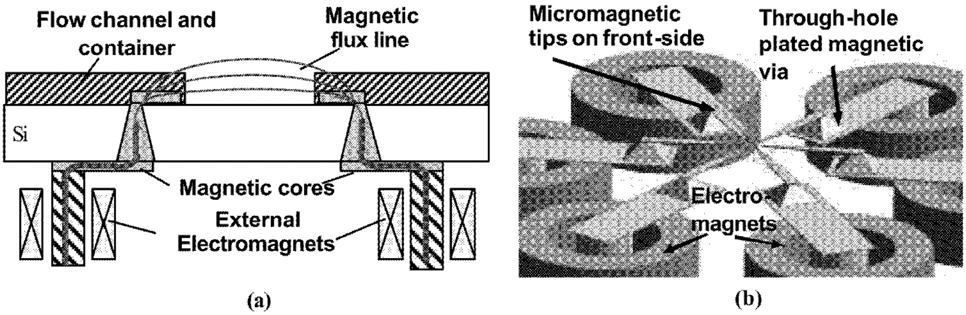


Figure 1. Schematic diagram of the magnetic mixer: (a) cross-sectional view and (b) the space view of the device.

2(b), (c), and (d)), the magnetic beads move around in the junction region of the channels with the applied magnetic field. Figure 3 shows an illustration of the proposed mixer. Two liquids with and without magnetic beads are introduced via separate channels. In the absence of excitation, the two fluids will flow separately according to laminar flow theory (Figure 3(a)). If sequential actuation is applied to the pole tips, the beads in the junction region will be agitated by both rotating and vibrating motion, which will then produce a rapid mixing action (Figure 3(b)).

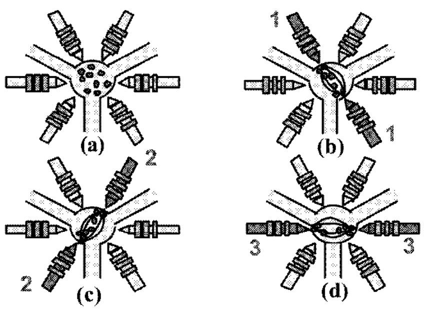


Figure 2. Working principle: (a) before excitation; (b); (c); and (d) excitation applied sequentially to three pairs of tips.

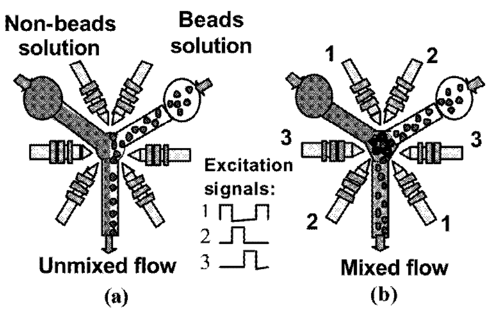
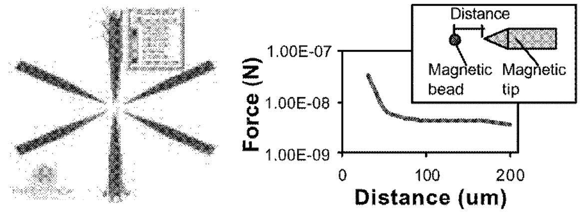


Figure 3. Mixing action of the mixer: (a) before and (b) after applying drive signal to the three pair tips.

Magnetic simulation for a 3-D micro mixer model was performed using INFOLYTICA magnet package. Figure 4(a) shows the magnetic field distribution generated at a magnetic tip pair at saturation state (1T). Permalloy, NiFe (81%/19%), was used as the magnetic core material including magnetic tips and vias. The permeability of permalloy was assumed to be 1,000. Figure 4(b) shows simulation results of the electromagnetic force exerted on a magnetic bead versus the distance between the bead (8.0 μm diameter) and the tip. The force on a single bead was simulated to reduce the complexity of simulating bead clumps. The simulation shows the magnetic force acting on the bead decreases quickly with increasing distance between the tips and the bead.

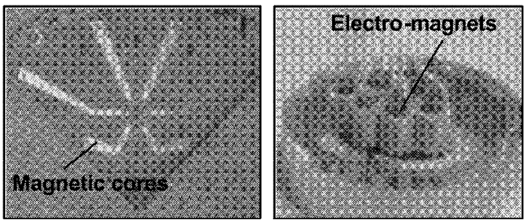


(a) (b)

Figure 4. Simulation results with one pair of tips at saturation state (1T): (a) B field distribution and (b) electromagnetic force exerted on one magnetic bead vs. the distance between the bead and magnetic tip.

FABRICATION

The fabrication procedures for the magnetic interconnection via, magnetic tips and the fluid channel have been reported [4,5]. Figure 5(a) shows the electroplated magnetic strips used for connection to electromagnets. Figure 5(b) shows the assembled prototype. Figure 6 shows the micro flow channel and chamber fabricated on the tips. The width and depth of the flow channel is 60 and 100 μm, respectively. The distance from the center of the channel junction and the tip is 100μm.



(a) (b)

Figure 5. Fabricated device: (a) backside view and (b) packaged device.

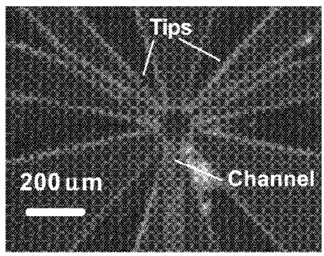


Figure 6. Fabricated flow channel made by SU-8 and magnetic tips.

EXPERIMENTAL RESULTS

Commercially available SPHERO^{TM} carboxyl-magnetic particles of 8.0μm diameter were used for the experiments. Figure 7(a) shows the magnetic beads randomly distributed before excitation. When a sequential driving signal with 300 mA at 0.3 Hz was applied to the electromagnets, the beads moved around within the junction region due to the rotating magnetic field generated by pole tips (Figure 7 (b)-(d)). Figure 8 shows the mixing effect generated by the magnetic bead mixer. Two liquid samples with and without magnetic beads were injected through two separate channels at a constant flow rate of 1 μl/min. With no applied excitation, the two injected liquids were not mixed in the outlet channel as shown in Figure 8(a). After a sequential driving signal was applied to the electromagnets, the magnetic beads within the channel junction region were agitated by the rotating magnetic field. This agitation includes bead motion of rotation and vibration, which effectively mixed the two liquids streams. Figure 8(b) clearly shows the function of the proposed chaotic micro mixer, demonstrating two separate liquids being completely mixed at the channel junction region.

CONCLUSION

In this work, a novel chaotic mixer for flow through mixing of magnetic beads has been successfully designed, fabricated and tested. The new magnetic mixer has magnetic tips on the front side and electromagnets on the backside of the wafer using an on-chip magnetic interconnection technique, which provides a compact size and reduces the interference effect between the functional tips and the exciting circuits. The micro mixer developed in this work shows fast and through mixing with small mixing volumes. The separation of electromagnets from the actuator tips allows for great flexibility in microfluidic system design and can be of great use to µTAS system development.

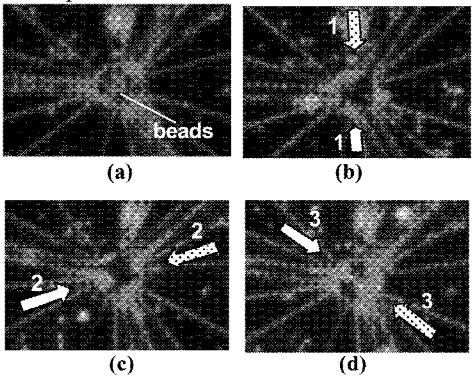


Figure 7. Microphotographs demonstrating the magnetic beads moving action: (a) no excitation applied; and (b); (c); and (d) sequential driving signal applied to three pairs of magnetic pole tips. (**Arrows indicate the excited pair tips**)

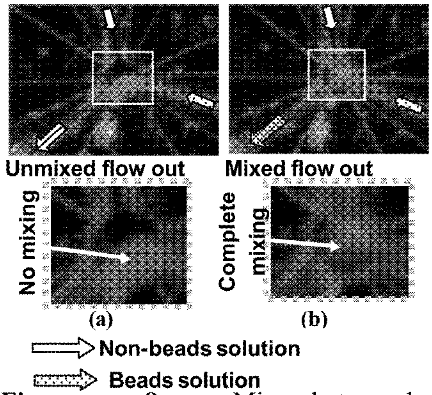


Figure 8. Microphotographs demonstrating the mixing action: (a) no excitation applied, and (b) solutions mixed by excitation of three pairs of pole tips. (**Inserts show magnified view of center**)

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