A study on the novel micromixer with chaotic flow

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ABSTRACT

Rapid mixing is essential for μ –TAS technology, but is often difficult to achieve it at low Reynolds numbers in a microsystem. For rapid mixing in a macrosystem, it is effective to mix with a stirrer. But, it is impossible to fabricate it in a microsystem. This paper presents the novel micro mixer with generated barrier embedded chaotic flow using a coupling between Lorentz force and the moving force of the electric charge in an electric field. Because the chaotic flow plays a role as a stirrer in a mixing chamber, the novel mixer was expected to mix more rapidly than existing micromixers. Most existing passive micromixers use the diffusion process. In this paper, we present computer simulation results about the flow directions in novel mixer and the experimental results with mixing visualization. Through the comparison with the mixing experiment by the diffusion process we confirm that the mixer has a simpler structure and is able to achieve high mixing efficiency.

Keywords: MEMS, micromixer, chaotic, Lorentz force, mixing, mixer

1 INTRODUCTION

The mixing is one of the most important processes, which occur in analytical microsystems. A good mixer should mix the liquids in small volume without taking much space. It is hard to effectively mix the fluids in microchannels, because the flow is mostly in a laminar regime and the only mechanism, which causes the reaction, is the molecular diffusion [1].

So many researchers improve the mixing efficiency using several methods. Effectiveness of a micro mixer can be improved by an active or passive mixing. An active mixing is achieved by additional moving or pumping devices. The active mixers use ultrasonic waves[2] or the forming nanoscale fluid jet[3]. Passive mixing does not need any additional devices and the proper shaping of mixing channel improves the mixing effectiveness. For example, passive mixing utilizes the geometrically spitting and recombining substreams[4,5]. An active mixer has higher efficiency than passive type mixer. But it is complex and expensive. So the passive mixer is generally used.

In addition, chaotic mixing in stroke flow regime can remarkably enhance the mixing efficiency[6]. Stroock *et al.* obtained the chaotic mixing by introducing an alternating velocity field [7].

The mixers mentioned above, have the special devices or the structures like a barrier. But the proposed micromixer doesn't have any structure for the barrier. It produces chaotic flow by using only buffer solution and magnetic force.

2 THEORY

2.1 Mechanism

The proposed novel mixer use two forces; Lorentz force and moving force of the electric charge in electric field. It can easily use electromagnetic force because the buffer solution in LOC (Lab on a chip) is electrolyte.

When the electrodes are charged, the plus(+) electric charge moves to the minus(–) electrode and the minus(–) electric charges moves to the plus(+) electrode. The electric charges get moving force in this way.

The Lorentz force is the force exerted on a charged particle in an electromagnetic field. The particle will experience a force due to electric field of qE, and due to the magnetic field qv × B. They give the Lorentz force equation (or law):

$$F=q(E+v\times B) \quad (1)$$

where E is the electric field, B is the magnetic field, q is the electric charge of the particle, v is the instantaneous velocity of the particle (in meters per second) and × is the cross product. Figure 1 is the schematic view of Lorentz force. Thus a positively charged particle will be accelerated in the same linear orientation as the E field, but will be curved perpendicularly to the B field according to the right-hand rule

2.2 Chaotic Flow

In the case of the helical flow, there exists one elliptic point in the cross sectional flow, as schematically shown in Figure 2(a).

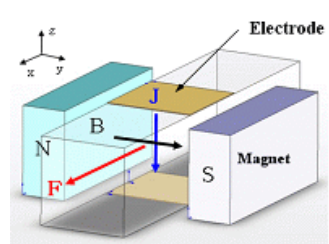
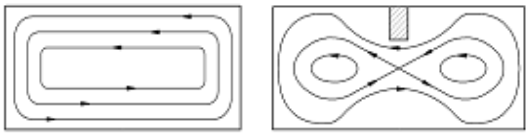


Figure 1 : Vector diagram of Lorentz Force



(a)Flow without barrier (b)Chaotic flow with barrier
Figure 2 : barrier embedded chaotic flow

With the barrier on the surface, the helical flow in the barrier zone is changed to a flow field containing two co-rotating flows, thereby being characterized by one hyperbolic point and two elliptic points, as indicated in Figure 2(b). The result in chaotic mixing with relatively low pressure achieves the high level of mixing efficiency of barrier embedded mixer. [8]

3 SIMULATION

3.1 Mixer geometry and simulation condition

For the accurate prediction about flow direction, we used commercial CFD code. As shown in Figure 3, an electrode was located. The dimension of the whole mixer devices is 10mm×10 mm. The sizes of the electrode are designed to 4mm × 4mm. And the gaps of two electrodes were set to 1mm.

For a numerical solution of CFD, operating conditions were set as follows. Initial temperature was 300K in micromixer. The magnetic flux was fixed at 5000G. Applied voltages were -4V and 4V, respectively. For practical prediction, electric conducing fluid, PBS solution is employed as the working medium in this simulation. As the working fluid for the real experiment applied to the analysis of protein, PBS buffer solution was used as medium for the fixation of protein. Table 1 tabulated the pertinent material properties of PBS solution.

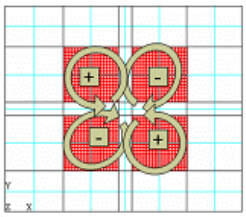


Figure 3 : Expecting path of second mixer

Density (kg/m^3)	1000
Conductivity (S/m)	1.5
Viscosity (Pa/s)	610^{-4}
Relative permeability	1
Relative permittivity	72

Table 1 : physical property of BPS solution

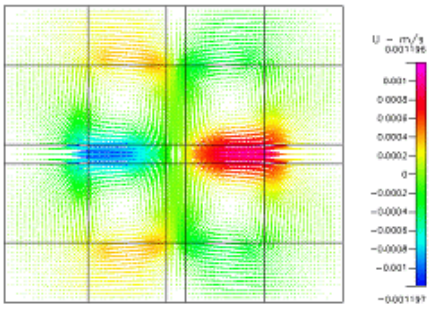


Figure 4 : A numerical simulation at fixed voltage

3.2 Simulation Result

As shown in figure 3, the arrows are predicted flow direction. Figure 4 is the simulation result of figure 3. If alternating voltage is applied in the mixer, the flow direction will be periodically changed. To confirm this idea, we set the opposite polarity. Figure 4 is numerical simulation result at AC voltage. It can confirm that the direction is changed. The periodical direction shifting improves mixing efficiency.

4 EXPERIMENT

4.1 Fabrication and experiment set-up

Figure 6 shows the schematic view of a novel micromixer. In order to maximize Lorentz force, permanent magnet should be well placed under Si wafer. The fabrication sequences are as follows. It started with single polished 500-μm-thick type (100) 4inch Si wafer. Initial 0.2-μm-thick thermal SiO_2 was grown. A thin oxide layer is then formed for the electrical isolation. Then metal electrodes (0.2-μm-thick Au) are deposited on a thin oxide layer using sputtering. Gold is commonly used as the electrode in LOC. Lastly we do photolithography process. Figure 7 shows the fabricated micromixer.

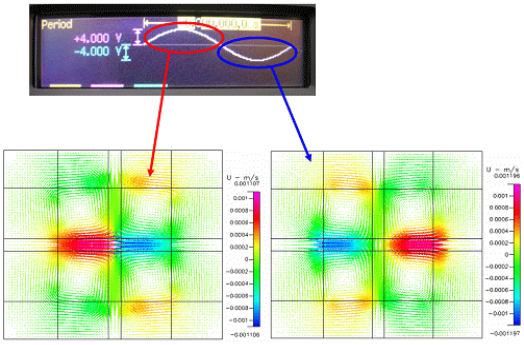


Figure 5 : A numerical simulation at AC voltage

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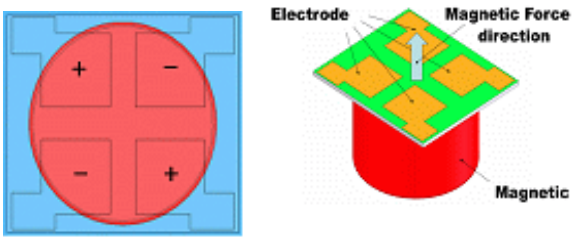


(a) Top view (b) schematic view of mixer

Figure 6 : schematic view of mixer

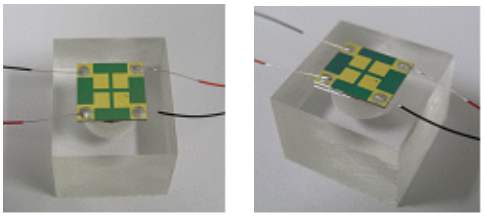


Figure 7 : fabricated micro mixer

To measure accurately, we used Hi-scope (KH-220, HiRox). Hi-scope could capture 1024 frames per second. Hi- scope was used to observe and record the mixing process. Hi-scope has a CCD camera, connected to computer with video capture software.

4.2 Experimental Results

Figure 8 shows the image of giving alternating voltage for 6sec. The alternating voltages are set to 4V and -4V, respectively. It confirms that the rotating direction is changed every 3 sec. It can figure out that the solution does not move same quantity in each electrode. This phenomenon occurs due to the mass difference in the positive charge and the negative charge. The positive electrodes move more powerful than the negative electrodes. And thus barrier embedded chaotic flow is produced. As mentioned in the introduction, this mixer doesn't include barrier part. On account of the mass difference of the charges, the negative electrode is employed as barrier in the mixer. Figure 9 shows the image of chaotic flow in a novel mixer.

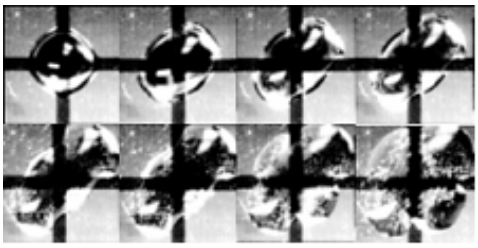


Figure 8: Image of a giving alternating voltage for 6 sec

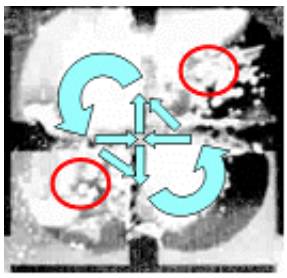
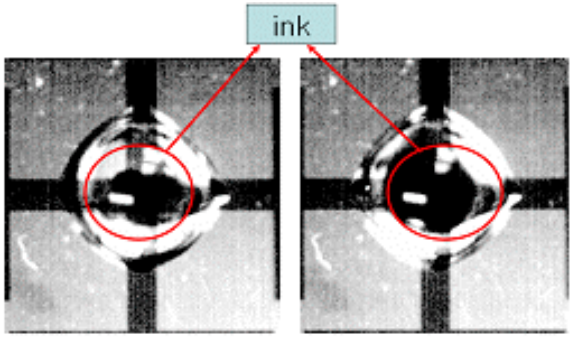


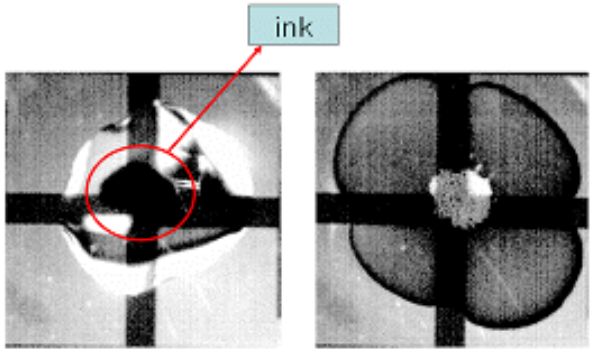
Figure 9: Barrier embedded chaotic flow in the novel mixer (red circle : barrier)

Figure 10 shows the photo shot at dropping time and after 15 sec, which shows the results of the mixing process of ink dropped into an electrolyte solution. Figure 11 is the photo which shows mixing with using a novel mixer in the same condition. Through the comparison with the mixing experiment by the diffusion process, we confirmed that the mixer had not only a simpler structure but also was able to achieve high mixing efficiency in spite of low power consumption.



(a) 0 sec (b)after 15sec

Figure 10 Image of dropping an ink into PBS solution



(a) 0 sec (b)after 15sec

Figure 11 Image of mixing an ink by a mixer

5 CONCLUSION

In this paper, we proposed a new chaotic mixing mechanism suitable in the micromixer and fabricated a chaotic micromixer. The experimental result shows high performance in spite of low power consumption and simple structure than existing micro mixer. We achieved 4 goals; periodical rotating and direction shift, non additional moiving part, working in a low voltage and simple fabrication process.

6 ACKNOWLEDGEMENT

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REFERENCES

[1] Adolph Fick, "On liquid diffusion," Journal of Membrane Science, Vol. 100, 33-38, 1995.

[2] Yang, Z., Goto, H., Matsumoto, M. and Maeda, R., "Active micro mixer for micro fluidic systems using lead-zinrconate-titanate (PZT)- generated ultrasonic vibration," Electrophoresis, Vol. 21, 116-119, 2000.

[3] Knight, J.B., Vishwanath, A., Brody, J.P. and Austin, R.H., "Hydrodynamic focusing on a silicon chip: mixing nanoliter in microsecond," Phys. Rev. Lett., Vol. 80, 3863-3866, 1998

[4] Wolfgang, E., Volker, H. and Holger, L., "Microreactors," Wiley, New York, 41-85, 2000.

[5] Schwesinger, N., Frank, T. and Wurmus, H., "A modular microfluid system with an integrated micromixer," Journal of Micromech. Microeng., Vol. 6, 99-102, 1996.

[6] A. Ajdrai, "Transverse eletrokinetic and microfluidics effects in micropatterned channels: Lubrication analysis for slab geometry," Phys. Rev. E, Vol. 65, 16301, 2002.

[7] A.D. Stroock, S.K. W. Dertinger, A. Ajdari, T.Mezic, H.A. Stone, and G.M. Whitesides, "Chaotic Mixer for microchannels," Science, Vol. 295, 647-651, 2002

[8] T.H. Kwon, D.S. Kim, S.W. Lee and S.S. Lee, "Barrier embedded chaotic micromixer" Proceedings IEEE 16th International Conference on MEMS 03, 339- 342, 2003