An Effective Passive Micromixer Employing Herringbone Structure

Category: 4 Biomedical and Chemical Micro Sensors and Systems

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ABSTRACT

This paper proposes a high efficient micro mixer, passively employing surface tension force as driving power and Herringbone structures as vortex generator for fluid mixing. The fluidic channel was designed without sidewall and confined with only the bottom hydrophilic and top hydrophobic surface for later-on mixing process among channels. Besides, in order to increase the mixing efficiency, herringbone-like structures are arranged on the bottom of the channel to enforce liquids to produce three-dimensional flow automatically. The fabrication has been completed successfully, and the testing result demonstrated 5 times higher mixing rate in 15mm mixing range. This device is anticipated to be batch-fabricated and applied to power-free μTAS or lab-on a-chip system in the future.

Keywords: hydrophilic, hydrophobic, herringbonelike

INTRODUCTION

Mixing in micro scale is a well known problem because Reynolds number is too low to generate turbulence. As a result, many mixing schemes, including zigzag channels [1], flow lamination [2], herringbone channel [3], or chaotic mixing [4], have been widely employed to solve this issue. Besides, there have been many actuation means to drive fluids in micro system, for example, by providing pressure gradient [5, 6], using thermal energies [7], or employing electrostatic force [8]. However, most of aforementioned mixers still required extra actuators like pumps [3] or external energies such as electrostatic or magnetic fields to drive the fluidic inside micro channel, and they usually need a large outside energy sources to support the desiring actuation, which greatly limit the capability of system integration. Therefore, for the sake of automatically producing mixing phenomenon without external driven means, capillary force is employed in this paper to drive fluid entering into micro channel with herringbonelike structures. These structures are the key factor to increase the mixing efficiency rapidly in the mixer because of the generation of three dimensional flow inside micro channel, greatly increasing fluid contact area for mixing.

As a result, a power-free device is proposed here employing only the surface tension energy defined by surface properties of the flow passages combined with herringbonelike concave structures to passively promote mixing effectively.

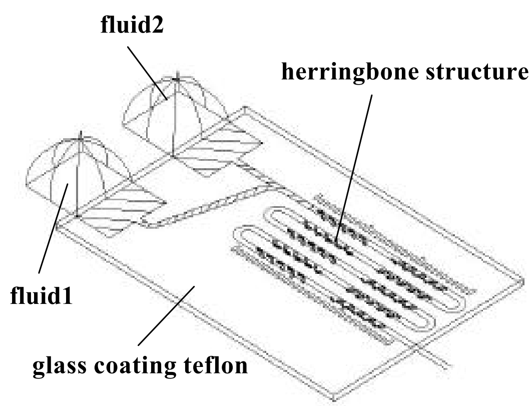


Fig 1. The surface-tension-driven micromixer with herringbone structures

DESIGN CONCEPTS

The design of the mixing device, as shown in Fig. 1, comprises a double fluidic entrance, and a winding channel confined by bottom hydrophilic patterns and a top hydrophobic surface employed to separate fluid in different channel temporarily, as the cross section shown in Fig. 2a.

When fluids are pipetted into the entrances, the pressure pushing-force established by the liquid puddle and the surface tension pulling-force generated by the hydrophilic side drag the fluids into the sidewall-free fluid passage, as shown in Fig. 2b. The advantage of that without sidewall is to reduce the frictional force on the interface between the fluid and the channel. Then, when two fluids are introduced into either liquid entrance, it will be driven automatically by surface tension into the winding channel and meet with each other for premixing.

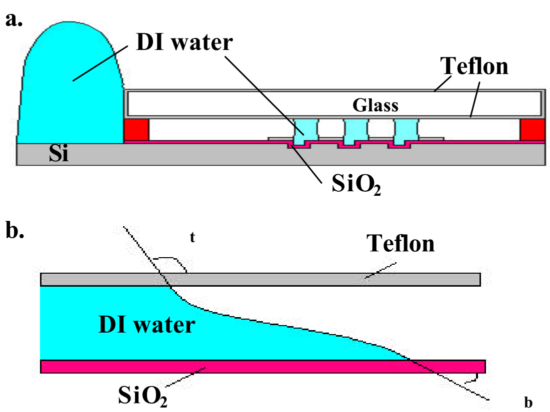
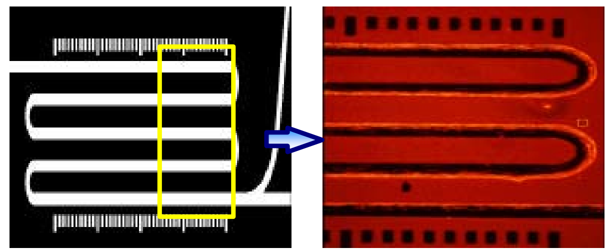
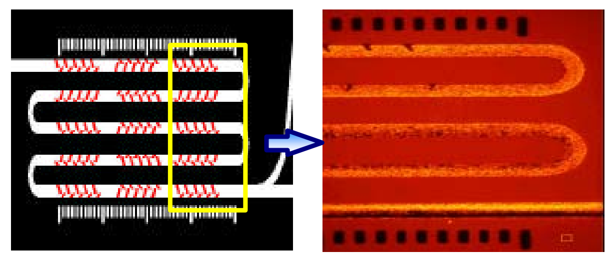


Fig 2. Cross section of the micro mixer and liquid driving method.

There are two different designs, one with smooth channel surface, and the other with herringbone structures, as shown in Fig. 3, are carried out for comparison. The purpose of the channel with herringbone structures is for rotating fluid in both spanwise and streamwise directions [3] to rapidly increase mixing surface by generating vortexes and decrease diffusion length by stretching fluid, thus effectively improving mixing in micro scale. In the herringbone design, the depth of the concave structure is also important in promoting mixing process. When the ratio of the herringbone depth to the channel height is between 0.2 and 0.3, it will reach the most excellent mixing efficiency. Thus the depth of the herringbone structure is selected to be 3 μm.



a. micro mixer with smooth channel designs.



b. micro mixer channel with herringbone structures

Fig 3. Fluidic mixing effect in different designs

FABRICATION

Fabrication process, as shown in Fig. 4, is performed by patterning Teflon on silicon wafer with SiO_2 coating as the bottom hydrophilic channel guide, and the cover glass slide coated with Teflon as a hydrophobic liquid separation layer.

First, the fabrication starts from the silicon substrate etching by Deep Silicon Reactive Ion Etch (DSRIE) for 3 μm, in order to define the position of the herringbonelike structures. Then Plasma Enhanced Chemical Vapor Deposition (PECVD) is used to deposit 1 μm oxide (Fig. 4a) for hydrophilic surface property. And 1% liquid Teflon (Dupont, USA) is then spun on the oxide surface for 0.5 μm

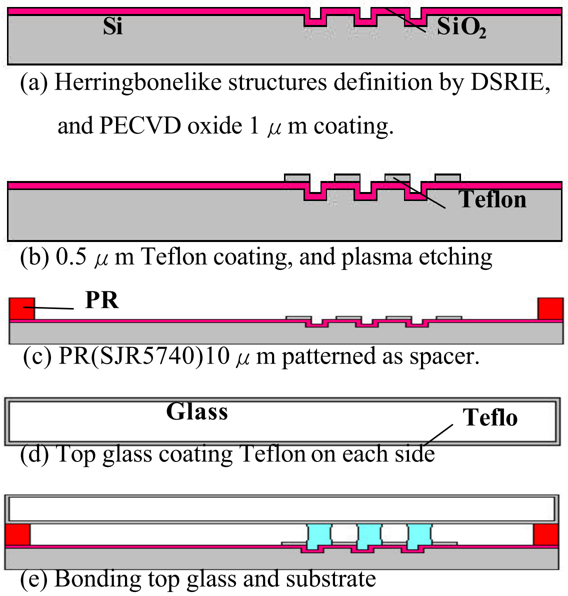


Fig 4. Fabrication process.

and patterned to form hydrophobic area (Fig. 4b). The process followed by Photoresist (SJR5740) patterning on silicon substrate as spacer for channel height definition (Fig. 4c), and Teflon coating on each side of the glass substrate (Fig. 4d) as the channel cover. Finally, The top and bottom substrates are bonded by photoresist with desired clearance, as shown in Fig. 4e.

EXPERIMENT RESULTS

To compare the ability of the mixing in the different designs, DI water and fluorescent particle mixture was pipetted into the micro channel, as shown in Fig. 3. First, the red fluorescent spheres (R900,Duke Scientific Corp.) were added into DI water to form working fluid. The concentration is 1% w/w, and diameter of the spheres is 0.93µm. Then the two work fluids were introduced into the entrance of the channel of 100 ?m wide and 2.5 cm long, and the liquid can be brought unto the end of the channel automatically without any other driving mean than surface tension. The velocity of the meniscus decreased from 1.7 cm/s to 0.5 cm/s due to the drag force increasing from the liquid-solid interface. The mixing process was visualized by a cooling CCD camera (DP50, OLYMPUS) under microscope (BX60M, OLYMPUS) , and the mixing process is shown in Fig. 3a.

The flow field in the smooth channel design, shown in Fig. 3a, formed only-laminar flow to the end of the channel. So the mixing effect is still not very conspicuous, it only has a little diffusion phenomena on the interface of the two liquids. However, another design with herringbone structures truly had very apparent mixing phenomena in the channels, as shown in Fig 3 b.

The detail mixing processes in different sections of the channels with herringbone structures are revealed in Fig. 5. The flow is laminar at the entrance region (Fig. 5a), but soon turn into vortex flow when passing through the herringbone region, and the particles start to scatter, as shown in Fig. 5b. The mixing rate reaches almost 45% when the flow distance approach 5 mm, as shown in Fig. 5c. Finally, it almost reaches fully mixing at the distance of 15 mm (Fig. 5d).

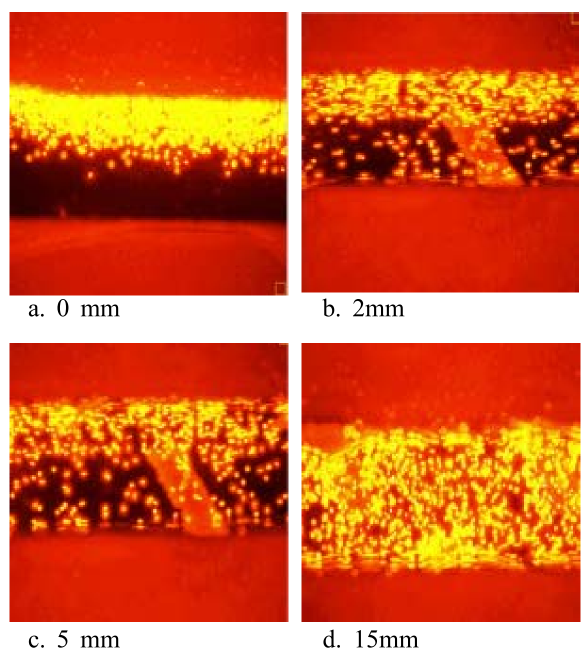


Fig 5. Photograph of the particle distribution on different positions of the herringbone channel.

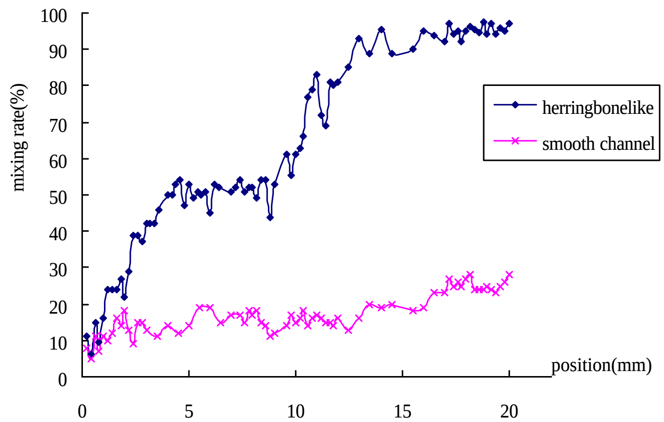


Fig 6. Mixing rate, on different positions for different channel designs.

The mixing rate for the mixers with or without herringbone structures was analyzed by image processing technique. The images were analyzed by ratio the area occupied by fluorescent particles to that of the whole channel to calculate the mixing effect, and the result is shown in Fig. 6. It's obvious that in the smooth channel, the mixing rate from the beginning to the end is always less than 20%, revealing a very poor mixing in this region. However, in the channels with herringbone structures, the mixing rate increases rapidly to about 100% at the end of channels because of the three-dimensional motion in particles. Thus it is almost 5 times better than that of smooth channel at the mixing distance of 15mm.

CONCLUSIONS

A power-free device is proposed in this paper employing only the surface tension energy defined by surface properties of the flow passages combined with herringbonelike concave structures to passively promote mixing effectively. Fabrication has been fully completely, and the designed hydrophilic channel area, hydrophobic spacer area, has also been demonstrated. Besides, the fluidic channel was designed without sidewall, it can increase the velocity of fluid flow in the channel. The testing results show that the mixing rate of the mixer with herringbonelike structures is 5 times better than that of smooth channel at the mixing distance of 15mm. This result is sufficient to prove that the herringbone structures in the micro channel can efficiently improve the mixing process efficiency. This device can be applied to power-free micro total analysis system or Lab-on-a-chip system in the future.

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REFERENCES

[1] Virginie Mengeaud, Jacques Josserand, and Hubert H. Girault, "Mixing Processes in a Zigzag Microchannel：Finite Element Simulations and Optical Study", *Analytical Chemistry*, Vol. 74, No. 16, August 15, 2002

[2] Jens Branebjerg, Peter Gravesen and Jens Peter Krog, "Fast Mixing by Lamination", *MEMS 1996*, pp.441-446

[3] Abraham D.Stroock, Stephan K. W. Dertinger, Armand Ajdari, Igor Mezic and Howard A.Stone, "Choatic Mixer for Microchannels", *SCIENCE, Vol. 295*, January 2002.

[4] Hiroaki.Suzuki, Chin-Ming Ho, "A Magnetic Force Driven Chaotic Micro-Mixer", *MEMS 2002*, pp. 40-43

[5] Branebjerg, J.; Gravesen, P.; Krog, J.P.; Nielsen, C.R.,"Fast mixing by lamination" 1996, Proceedings IEEE MEMS '96, pp. 441 -446. 1996.

[6] Deval, J. ;Tabeling, P.; C.M. Ho, "A dielectrophoretic chaotic mixer Deval" Proceedings IEEE MEMS' 02, pp. 36-39, 2002.

[7] Thomas K.Jun and C.J.Kim, " Valveless pumping using traversing vapor bubbles in microchannels", Journal of Applied Physics, Vol 83, No.11, 1 June 1998.

[8] Junghoon Lee and C.J. Kim," Liquid Micromotor Driven By Continuous Electrowetting", Proc. 1998 IEEE MEMS Conference, pp.538-543, Heidelberg, Germany, 1998.