ASEE 2014 Zone I Conference, April 3-5, 2014, University of Bridgeport, Bridgpeort, CT, USA.

Design and Simulation of an Electrostatically-Driven MEMS Micro- Mixer

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Abstract—Bio MEMS (Biology Micro electro mechanical Systems) focus on some micro-fabricated devices including electrical and mechanical parts to study the biological system. Especially some micro-liquid handling devices like micro-pumps, active and passive micro-mixers that can make two or more micro-fluids mixing completely, with the chaotic advection. This kind of rapid mixing is very important in the biochemistry analysis, drug delivery and sequencing or synthesis of nucleic acids. Besides, some biological processes like cell activation, enzyme reactions and protein folding also require mixing of reactants for initiation, electrophoresis activation. Turbulence and inter-diffusion of them play crucial role in the process of mixing of different fluids. In this paper, the design of a new kind of electromechanical active micro-mixer, which includes two inlets and one outlet under the electrostatic driven voltage is presented. Two different fluids will enter the micro-mixer and shows different colors separately blue and red. Choosing the ANSYS for the simulation of the fluids running in the micro-mixers, we can see nearly 100% fluids that have been mixed. ANSYS is used to show the effectiveness of the micro-mixer.

Keywords—Bio MEMS, Micro-Mixer, ANSYS simulation

I Introduction

Nowadays with the development of MEMS technology, there are some equipment which we use on the biology analysis , experiment tests, chemistry industry, especially some equipment which we use on the biomedical technologies such as micro-pump, micro-filter, micro-valve, micro-mixer, micro-actuator, micro-sensor, micro-reactor, micro-channel, just trying to narrow down those equipments to micro-scale, mainly integrating these micro-scale facilities into a lab-on-a-chip for the aims of bio-chemical disposal, diseases diagnose, analytical examination, new drug development and monitoring environment and so on [1] .

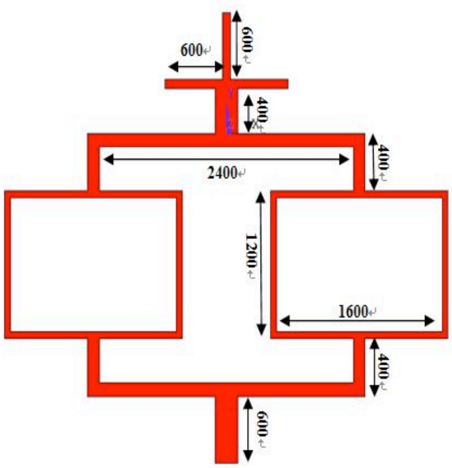
The micro-technology can make the mixing of micro-fluidics be more well-distributed and faster than any other normal mixing equipment, especially in the areas of chemical synthesis, emulsion liquid preparation. According to the Flick law, increasing the contact area between two different fluids can accelerate the mixing. So we just generate the turbulent flow that we can the effects of mixing. In this paper, the Reynolds number is far less than the Reynolds number when turbulent occurs. The final aim is how to make two or more different fluids mix completely and enhance the efficiency.

II Micro-Mixer Design

Micro-mixers can be separated into two different kinds including: active and passive. In active micro-mixers, some controlled movable parts or external disturbances will be integrated into the system. There are some classic external powers such as: pressure gradient, temperature gradient, electric field force, magnetic force, thermal convection and acoustic wave so on. The advantage of using the active micro-mixers is that some movable elements or additional disturbances can be controlled to obtain effective mixing.

Another kind of micro-mixers is passive micro-mixer. In passive micro-mixers, it just utilizes the change of geometrical shape of channels or characteristics of micro-fluidics to advance the mixing results. The principle of this kind of micro-mixers is that it depends on the molecular diffusion, chaotic advection or turbulence effect without using external disturbances. The passive micro-mixers are cheaper than the active micro-mixers and require suitable for high efficiency.

The passive Micro-mixer model and the parameters are shown in Figure1



Parameter	Dimension
Inlet Channels	80 μm
Secondary Vertical Channel	240 μm
Horizontal Channel after secondary channel	120 μm
Central/ Passing Rectangular Channels	60 μm
Horizontal Channel Near Outlet	120 μm
Outlet Channel	240 μm

III Working Principal

In passive micro-mixers, they can disturb the micro-fluids without external energy but only need the diffusion or chaotic advection. Whereas, the active micro-mixers need using external power including pressure, temperature, electrohydrodynamics, dielectrophoretics, electrophoretics, electrokinetics, magnetohydrodynamics and acoustics to work. After integration with these external fields, the structures of active micro-mixers are often complicated and the process of fabrication is complex. In contrast, passive structures are stable to operate and easily integrated in a system.

Generally speaking, passive micro-mixers mainly increase diffusion and convection of molecules to change the geometric shape, and then expand the micro-fluids contact surface and mixing efficiency. So the shapes of passive micro-mixers usually are very complicated and it is a little difficult to fabricate.

The passive micro-mixier has 3 inlets (1 vertical inlet and 2 horizontal inlets) and 1 outlet. It can effectively mix up to 3 different microfluid flows. Microfluid flows from 3 inlets are first mixed into one channel, then divided into 2 branches and then further divided into four sub-branches. After that, the flows from 4 sub-branches are mixed back into two branches, and finally rejoined back into one channel and flow out of the outlet. By introducing many rounds of turn-overs, turbulence is induced each time when microfluid flow changes its flow direction. The total length of the micro-mixer is about 20480 μm. The channel width are also dynamically adjusted to adapt to different amounts of microfluid flow along the channel. For example, if multiple branches are joined together, the corresponding channel is enlarged to accommodate the increased microfluid flow. If a channel is divided into multiple branches, the corresponding branches are narrowed to adapt to the reduced microfluid flow.

The fabrication process of micro-mixers are shown in figure 2:

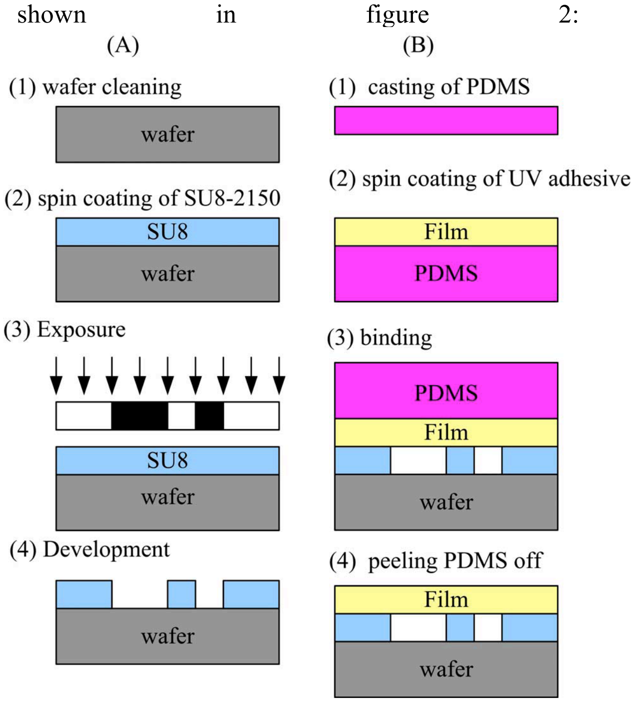


Figure 2 The fabrication procedure of the micro-mixer [23]

V Analysis And Performance of Design

Assume the microfluid flow in vertical inlet (labeled as fluid A) contains a protein like solution like and the concentration is set to 1. The microfluid flow in two horizontal inlets (labeled as fluid B) is the same

IV Materials and fabrication process

The main material which is used to fabricate the micro-mixers is PDMS, which has high bio-compatibility with the biology carrier, easy to be made and is transparent, non-toxic and suitable to the optic examination. Besides, silicon will be used to form the actuators which would be integrated into some active micro-mixers. Glass, ITO, gold and polyester are suitable substrate materials.

and its concentrations is set to be 0 (i.e. pure water). Based on microfluid dynamics analysis, we estimate the mixing efficiency as well as the intensity of segregation and variation coefficient of the microfluid flows inside the mixer. In addition, Reynolds number is also a very important factor of fluid flow to measure the ratio between inertial and viscous forces in a particular flow. For Reynolds number below 2100, we get laminar flow in which the fluid molecules travel along well-ordered non-intersecting paths or layers. When Reynolds number is over 4000, we get turbulent flow that fluid molecules from adjacent layer become totally mixed. For microfluidics, generally we get laminar flow.

Reynolds Number is calculated as:

The equation of Mixing Efficiency:

where Ci is the mole percentage of the No. i dot in a certain area, n is the number of style points in a certain cross section,is the ideal mole percentage, C_i is a number in range from 0 to 1. When C_i is 0.5, it indicates A fluid and B fluid are mixed completely.

The Intensity of Segregation and Variation Coefficient:

$$V_c = \sigma_0 / x_v \quad I_s = \sigma_0^2 / \sigma_i^2$$

σ_i and σ_0 are the standard deviation of the mass fraction of species at the inlet and outlet of micromixer, x_v is the mass fraction of species at the inlet

VI Results and Discussions

ANSYS FEM simulation is used to verify the function of the MEMS mixer. The velocities of both of species 1 and species 2 at inlets are set to be 1000μm/s (boundary condition). Density of species 1 and 2 are set as 1g/cm^3 and 1.5 g/cm^3 respectively. Our calculation shows that the Reynolds number of the microfluid flows is under 10, which belongs to laminar flow. The meshed ANSYS model of the MEMS mixer is shown in Fig. 3.2 B. The contour plot of the flow density is shown in Fig. 3.2B. From Fig. 3.2B, we can clearly see how both microfluid flows are mixed rapidly along the channels. The light blue (1.444) and yellow (1.000) colors represent microfluid species 1 and 2 respectively. Once both fluids are thoroughly mixed, its color becomes uniform dark blue (1.333).

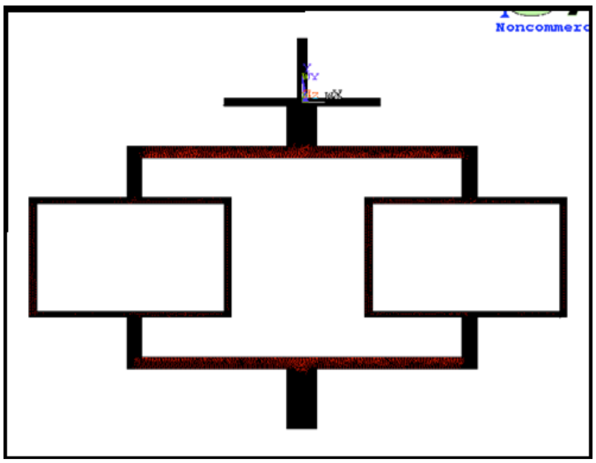


Fig.3. 2A Meshed ANSYS model of mixer

$$R_e = \rho V_{ref} L_{ref} / \mu$$

$$\sigma = \left[1 - \sqrt{\sum_{i=1}^{n} \frac{(C_i - C_\infty)^2}{n}} / C_\infty \right] \times 100\%$$

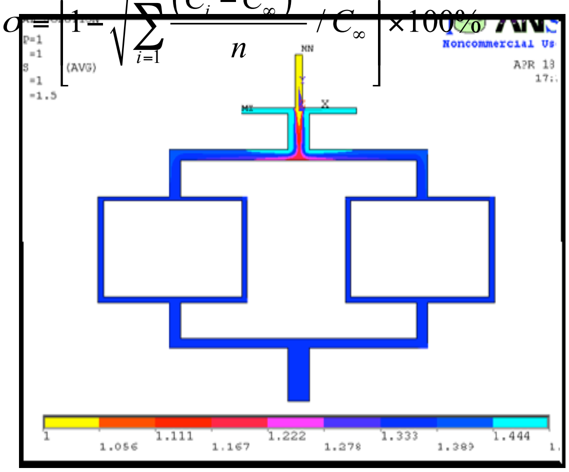


Fig. 3.2 B Contour plot of density distribution

The mixing can be verified not only from density contour plot, but also the density path plot along the cross section of the inlet and outlet. The ANSYS simulated density distribution plot along the cross section of the first top vertical channel section near the inlets is shown in Fig. 6. We observe that the microfluid is not well mixed yet at this time, because there are more species 1 in the middle, and more species 2 in both sides close to the channel sidewalls. After passing the MEMS mixer, the density path plot along cross section of outlet is shown in Fig. 4. It shows the microfluids (species 1 and 2) are now thoroughly mixed, and a uniform density distribution is achieved.

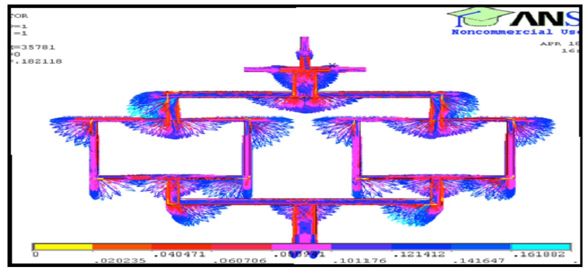


Figure 3.2 C Ansys Fluid Velocity Vector Plot

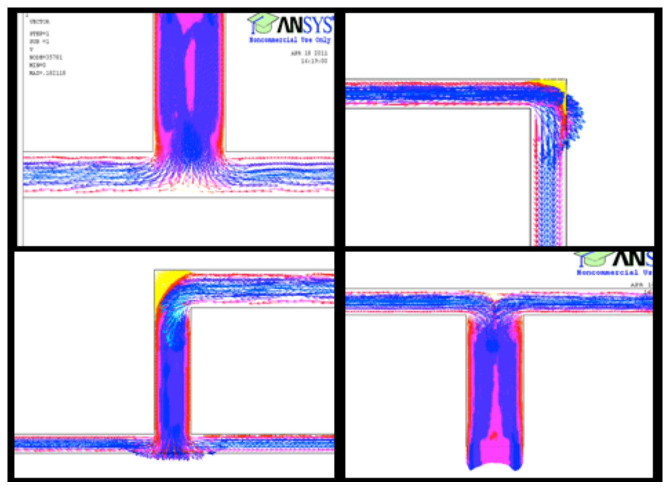


Figure 3.2 D Local View of Induced Turbulence

The mixing can be verified not only from density contour plot, but also the density path plot along the cross section of the inlet and outlet. The ANSYS simulated density distribution plot along the cross section of the first top vertical channel section near the inlets is shown in Fig. 6. We observe that the microfluid is not well mixed yet at this time, because there are more species 1 in the middle, and more species 2 in both sides close to the channel sidewalls. After passing the MEMS mixer, the density path plot along cross section of outlet is shown in Fig. 4. It shows the microfluids (species 1 and 2) are now thoroughly mixed, and a uniform density distribution is achieved.

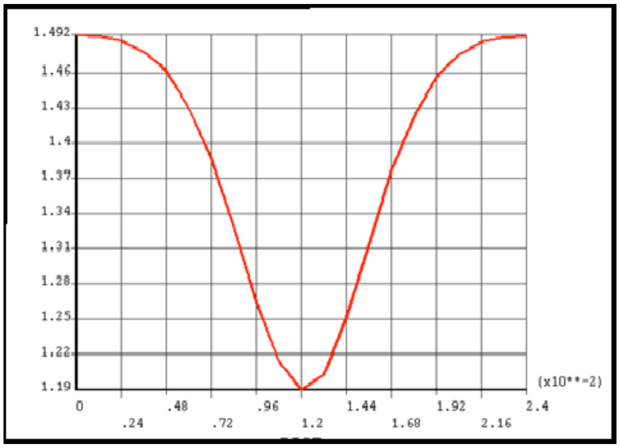


Figure 3.2 E Density Distribution Near Inlet

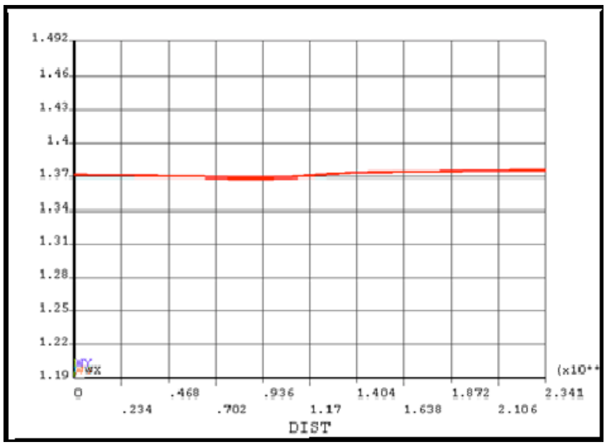


Figure 3.2 F Density Distribution at Outlet

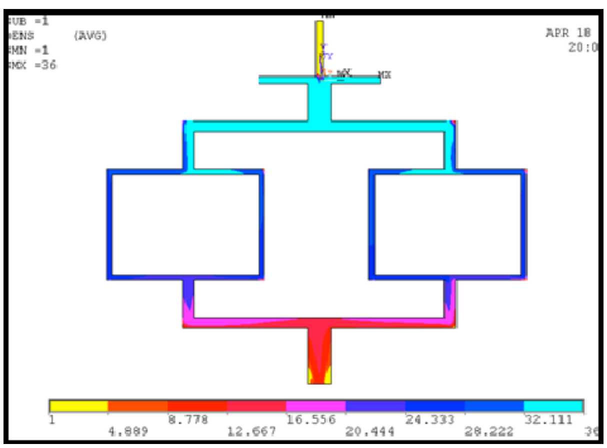


Fig. 3.2G Density plot (ρ2=35g/cm3)

Furthermore, we also simulated the case when the density of species 2 is changed from 1g/cm^3 to 35g/cm^3, the result is shown in Fig. 3.2G. Compared with result in Fig. 3, we can see that as the initial density different among input microfluid becomes larger; it takes longer distance for both microfluids to thoroughly mix with each other. This indicates it's more challenging to mix two microfluids with larger difference in its properties.

VII Conclusions and Future Work

Here in this report, a new electrostatic driven micro-pump mixer is introduced and integrated with the resonant plate in the channel of micro-mixer to advance the mixing efficiency, however, the effective micro-pump mixer in this report is very simple and just two inlets and one outlet. This kind of micro pump-mixer can be used in mixing both liquid and gas. In this report, I just set up the electrostatical activated resonant plates (there are two plate paralleled with the bottom of the chamber) near the bottom of the main rectangular micro-fluid chamber to enhance the mixing of two kinds of micro-fluids when the fluids are running out the mixer, then there would be a vortex around the tip of two plates. After adding an external electrode to apply on the resonant plate, we can get an optimum maximum displacement: 0.5407E+00,that shows the higher effectiveness with an external power than without additional power.

In the future, I will further do some research about how to make the micro-fluidic mixer mixing more efficient than this one, that means to change some external power including the voltages of the external electrode, location of the electrode; except these, I will try many other shapes of micro-fluidic mixers or to change the conditions for setting the mixing plates which in the channels, like the location and the quantity of the plates. However, there are many ways to make the micro-fluidic mixer better, they should not be too expensive in application.

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