

# An Active Mixer with Vertical Flow Placement via a Series of Inlets for Micromixing

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**Abstract**—Flows in a microchannel are laminar, which means that mixing depends on only inter-diffusion. A micromixer plays an important role in obtaining fast diagnosis results in the fields of m-TAS (total analysis system), Bio-MEMS and LOC (lab-on-a-chip).

In this paper, we propose a new active mixer with vertical flow placement via a series of inlets for micromixing. This has two inlets on the same axis, one of which is located before the other. The sample input by the first inlet flows into the down-position, while the other sample by the second inlet flows into the up-position. In the experiment, the samples were located vertically in up-down positions in a micro chamber. PZT was attached below a chamber, and ultrasonic waves were radiated in the down to up direction towards the samples in the micro chamber in order to accelerate the mixing. The mixing process was measured by the change of color in a micro chamber using phenolphthalein and NaOH. The results of the experiment showed that the samples in the microchamber were efficiently mixed and that our new active mixer was superior to the horizontal type of active mixers in view of the grey levels and the standard deviation.

**Keywords**—Active mixer, vertical flow placement, microchannel, bio-MEMS, LOC.

## I. INTRODUCTION

SINCE the introduction of MEMS technology into the bio-science field, the miniaturization of diagnostic devices has been attracting considerable attention. Such miniaturization could reduce the usage of specimens and reagents, and the sensitivity of experiments could be improved [1], [2]. However, fluid in microchannels shows a laminar flow due to the small Reynolds number, with the result that more time is required for the mixing of the reagents. To solve this problem, passive or active micromixers are used. A passive micromixer mixes reagents using the shape of the flow channel without any external energy source. Therefore, recent studies have focused on the increase of the contacting area between the reagents. Passive micromixers are advantageous for the miniaturization of the device, because no additional power or device for element control is required. The weak points of passive micromixers include: the greater influence of the flow speed and the ratio between the reagents on the mixing time; and the degradation of the homogeneity of the reagents, which is caused by a drop in pressure in the direction of the flow.

To solve these problems, studies are being conducted on the active mixers that make use of the piezoelectric element, which is an external energy source [3]-[5]. Active mixers offer stable

and reliable performance and are easier to control as regards the mixing effect. This study presents a new active-type mixer wherein the reagents are positioned in upper and lower positions in a micro chamber and then mixed with ultrasonic waves. While it is easy to arrange the reagents which enter the macro-channel in vertical positions, such an arrangement is very difficult in a microchannel whose height is very small. In this study, the reagents in the micro chamber were positioned vertically (upper and lower) by arranging the inlets of the reagents in series. The mixing process of the fabricated, vertical-type active mixer was examined according to the change in the colors of the phenolphthalein and NaOH. The superiority of the proposed active mixer to the passive mixer was verified by via comparison of the test results obtained by using the same piezoelectric element.

## II. NUMERICAL SIMULATIONS

Since the arrangement of the reagents in the chamber has a considerable influence on the performance of the mixer, we developed a method for the easy rearrangement of the reagents by varying the sizes and positions of the inlet and outlet of the mixer. Mixers, in the reagents were arranged horizontally (in the left and right positions) and vertically (in the upper and lower positions), were named as horizontal and vertical active micromixers, respectively. Under the assumption of laminar flow condition, the influence of the size and position of the inlet on the position of the reagents was examined using CoventorWare. When the inlets (1, 2) through which the different reagents entered were arranged from left-right, as shown in Fig. 1, the reagents in the chamber were arranged horizontally. When the inlets (1, 2) were arranged in series, as shown in Fig. 2, the reagents in the chamber were arranged vertically. However, the inner diameters of the inlets must be the same as the width of the flow channel; otherwise, the reagents cannot be arranged in upper and lower positions uniformly within the chamber, which leads to a decrease in micromixing efficiency.

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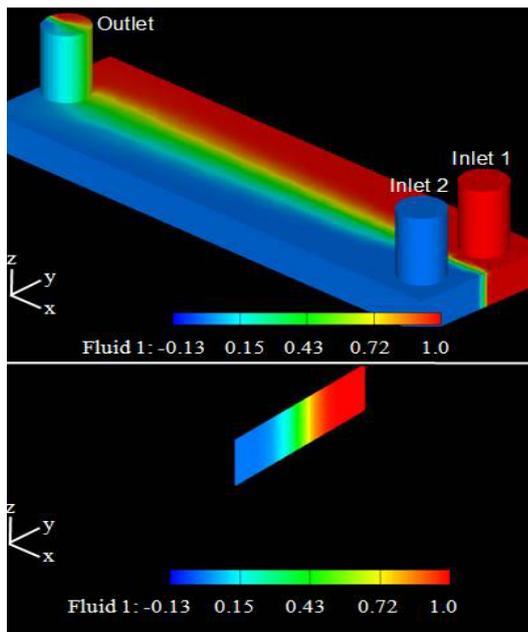


Fig. 1 Fluids in the left and right positions

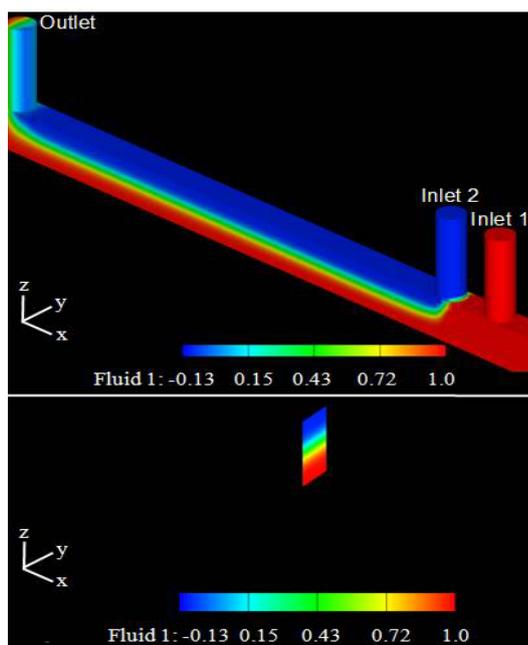
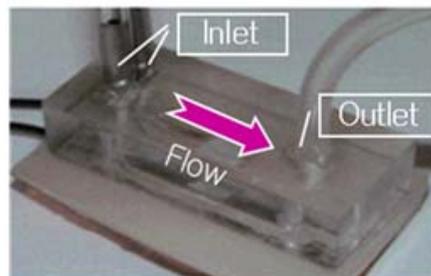


Fig. 2 Fluids in the upper and lower positions

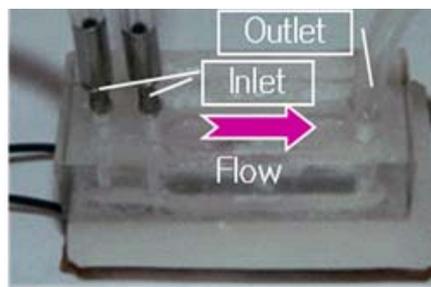
### III. EXPERIMENTAL SETUP

An active mixer, as shown in Fig. 3, was designed and fabricated to test and investigate the mixing processes of the horizontal and vertical active mixers. Figs. 3 (a) and (b) show horizontal and vertical active mixers, respectively. In both mixers, the reagents enter through the inlets 1 and 2, pass through the mixing chamber where the ultrasonic waves are applied, and are then discharged through the outlet. Inlets 1 and 2 in Fig. 3 (b) were designed to enable the different reagents

which would be mixed in the mixing chamber to be arranged vertically. The width and thickness of the channel were 5mm and 1mm, respectively. A PZT with a thickness of 150 $\mu$ m was installed on the bottom of the mixing chamber to radiate ultrasonic waves upwardly to the interface of the two reagents. The thickness of the channel can be easily made in a micro size as necessary. A smaller thickness of channel is more advantageous in terms of shortening the mixing time.



(a) Horizontal type of active mixer



(b) Vertical type of active mixer

Fig. 3 Photographs of the active mixers.

A test apparatus was fabricated, as shown in Fig. 4, to test the performance of the active mixers. The test apparatus comprised a frequency generator, a power amplifier, and a CCD. The frequency generator generates and supplies sine waves to the piezoelectric device which have the frequency of 300kHz. The signal generated in the frequency generator is amplified in the power amplifier up to 50Vp-p to drive the piezoelectric device. Phenolphthalein and NaOH were used as the reagents to test the mixing performance of the chamber of the active mixers. Phenolphthalein, which is colorless, turns to red when reacting with alkalis such as NaOH. Therefore, the degree of mixing can be monitored according to the change in color observed in the chamber using the CCD.

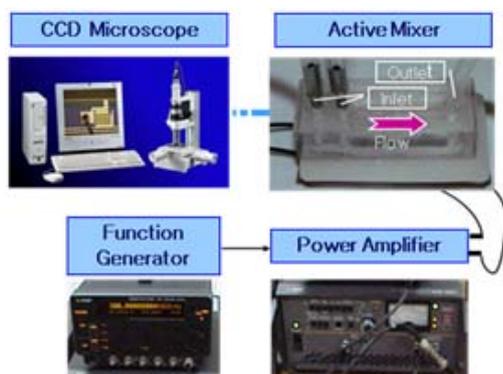


Fig. 4 Performance test system

#### IV. RESULTS AND DISCUSSION

In order to test the performance of the fabricated horizontal and vertical active mixers, the degree of mixing at the same flow speed was monitored using a CCD. The impedance according to the frequency of the piezoelectric device was measured. Fig. 5 shows the measurements. The level of impedance at the frequency of 300kHz applied in this test was 233.7 $\Omega$ . The same piezoelectric device was used in both the horizontal and vertical active mixers.

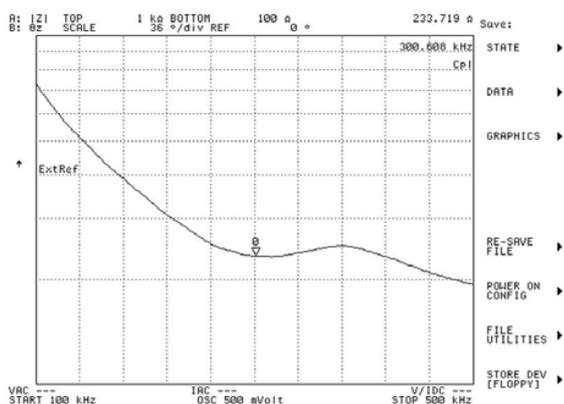


Fig. 5 Characteristics of impedance

As shown in Fig. 6, at 0 seconds, when ultrasonic waves were not applied, the horizontal active mixer showed a red strip in the center, which thickened as it approached the outlet. This means that the reagents were observed in the center only. While approaching the outlet, the thickness of the red strip increased according to the increase in the time of contact between the reagents. As shown in Fig. 7, at 0 seconds, the vertical active mixer showed a red color distributed uniformly across the micro chamber, which means that the two reagents were in uniform contact with each other, forming vertical layers. When ultrasonic waves were radiated, the red-colored area of the horizontal active mixer widened, as shown in Fig. 6, and the whole red-colored area of the vertical active mixer became darker, as shown in Fig. 7.

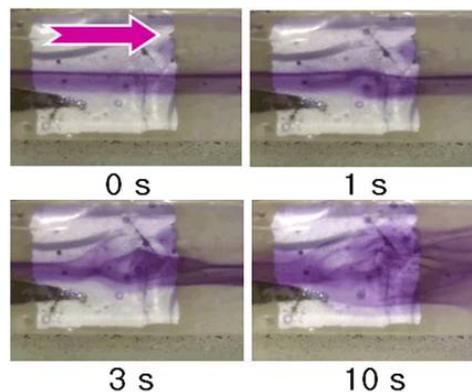


Fig. 6 Visualization of the mixing state of the horizontal-type active mixer

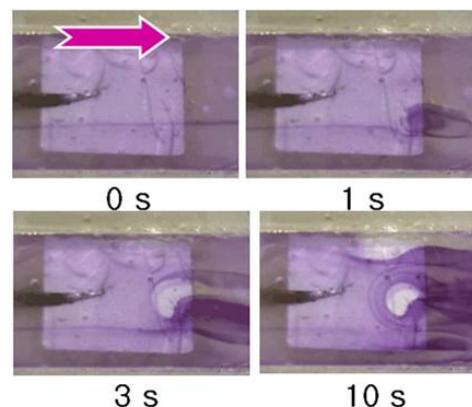


Fig. 7 Visualization of the mixing state of the vertical-type active mixer

The color distribution in the outlet side, as shown in Fig. 7, shows that the red color in the vertical active mixer is more uniform across a wider area than that in the horizontal active mixer. In order for a more detailed investigation of the color distribution, the color on the outlet side of the piezoelectric device was quantified, the result of which is illustrated in Fig. 8.

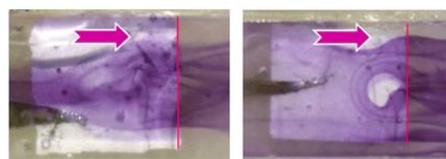


Fig. 8 Measuring position for grey level

The average value and the standard deviation of the brightness of the reagent mixture at the outlet are presented in Table I. The average and the standard deviation of the vertical type are smaller than those of the horizontal type. The smaller average value represents relatively better mixing while the smaller standard deviation represents more uniform mixing with reference to the mean, at the outlet.

TABLE I

GREY LEVELS OF THE HORIZONTAL (LEFT-RIGHT) AND VERTICAL (UP-DOWN) TYPE ACTIVE MIXERS AT THE SAME OUTLET POSITIONS AFTER 10s

Type	Min.	Max.	Mean	Standard Deviation
Left-right	46	210.7	103.1	40.0
Up-down	41	143.7	84.6	22.3

## V. CONCLUSION

This paper presents a new vertical-type active mixer for application in the micromixing process. The performance of the new mixer designed and fabricated in this study was tested using phenolphthalein and NaOH. The results of the test showed effective mixing. In addition, with the same piezoelectric device, the vertical-type active mixer showed better performance than the horizontal-type active mixer, which was proven by the analyses of the changes and standard deviation of the colors of the reagents at the outlets of the mixers. It is expected that this active mixer will be applied to integrated-type diagnostic devices which make use of micro elements.

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