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마이크로믹서에의 응용을 위해 PMN-PT를 이용한 경계면과 수직방향 방사형 믹서

(Cross-sectional Radiation Type Mixer into the Boundary Surface using PMN-PT for Micromixing)

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(Pil Woo Heo, Eui Soo Yoon, and Kwang Sik Kho)

요 약

마이크로믹서는 Bio-MEMS 혹은 μ-TAS 분야에서 중요한 역할을 수행한다. 혼합은 두 유체의 난류 상태와 상호확산에 의해 발생된다. 마이크로채널 내에서는 레이놀즈수가 작기 때문에 (Re << 2000) 난류가 발생되기 어려우므로 주로 상호확산에 의해서만 혼합된다. 따라서 두 유체가 적정하게 혼합되기 위해서는 긴 채널이 요구된다. 본 논문에서는 혼합에 소요되는 길이를 줄이기 위해서 PMN-PT에 의해 발생된 초음파에 의해 혼합되는 새로운 믹서를 제안하였다. 챔버 내에 발생된 초음파는 두 유체에 의해 생성된 경계면과 수직한 방향으로 방사된다. 사용된 두 유체는 상하방향으로 경계층을 이룬다. 혼합 상태는 NaOH와 페놀프탈렌의 반응에 따른 색상 변화를 관찰하여 측정하였다.

Abstract

A micromixer plays an important role in Bio-MEMS or μ-TAS. Mixing is generally generated by turbulence and interdiffusion of two fluids. Because of low Reynolds number values (Re << 2000) within microchannels, it is difficult to generate turbulence, and consequently mixing mainly depends on interdiffusion. So, channel distance is often prohibitively long to mix two different fluids properly. To reduce this mixing length, we proposed a new mixer for micromixing in which two fluids were effectively mixed by an ultrasonic wave generated by PMN-PT. The ultrasonic wave was radiated into a chamber in the cross-sectional direction into the boundary surface formed by two fluids. The two fluids were positioned one on top of the other. The mixing state was measured by observing the color of samples due to the reaction of NaOH and phenolphthalein.

Keywords: Mixer, Micromixing, PMN-PT, Bio-MEMS, μ-TAS

I. Introduction

Several studies related to micromixers have been recently executed in the areas of bio-MEMS and μ-TAS. A micromixer requires small size and fast speed for processing. However, the flow is laminar due to low Reynolds number values, and consequently the two fluids are mixed only by interdiffusion through the interface area. As such, a long time is required for mixing.

To solve this problem, various kinds of passive mixers that do not require an external source have been examined. These are simple and cheap, and it is desirable to manufacture them in a small size. The structural enhancement of micromixers makes it possible to increase the interface area and generate turbulent flow and mixing efficiency is thereby increased [1-3].

However, in a passive micromixer, mixing time depends on flow rate and the pressure drop through

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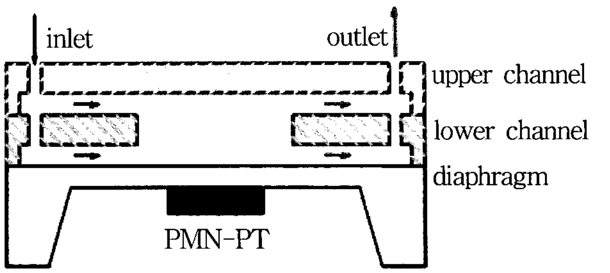
the channel has an effect on the homogeneous state of mixing. Furthermore, this device has increased flow resistance in the channel and is sensitive to gas bubbles. Hence, a stable and reliable active micromixer that has an external source is required. In this paper, we propose a new mixer for micromixing that utilizes ultrasonic waves. Studies on micromixers using ultrasound have been reported since the early1990s [4-6]. Monnier et. al examined micromixing by ultrasound on a molecular scale [7]. Micromixing by acoustic cavitation and streaming was found to be more favorable at a lower frequency. Greater acoustic intensity afforded lower mixing time, and high viscosity was unfavorable for mixing.

Yang et. al reported the first ultrasonic micromixer using lead-zirconate-titanate (PZT) [8]. This active mixer was operated at 48 kHz frequency and the ratio of fluids for mixing was controlled by controlling the applied pressure. Yang et. al also reported an active micromixer operated at 60kHz frequency, the performance of which was investigated with a microscope with fluorescent materials [9]. They showed the mixing state by measuring the intensity distribution due to the fluorescent materials against a position around the outlet. However, in this study, we consider that there is little loss in terms of mixing of fluids in relation to the direction between the interface surface of two fluids and ultrasonic radiation.

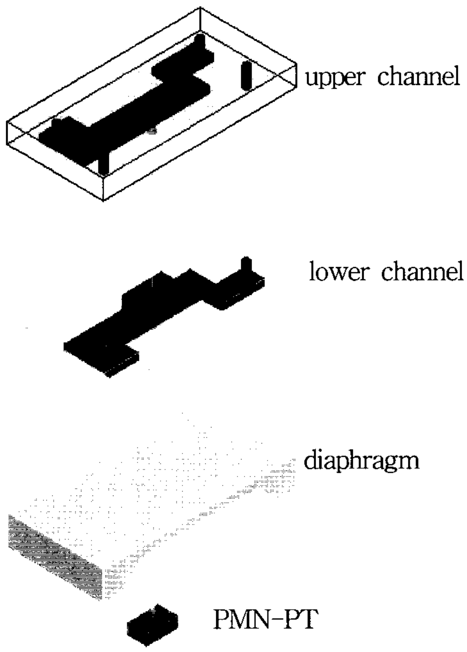
Thus, we proposed a new mixer for micromixing with a PMN-PT ($Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$) having a higher piezoelectric constant and lower driving voltage. An ultrasonic wave was radiated into a chamber in the cross-sectional direction into the boundary surface formed by the two fluids. The two fluids were positioned one on top of the other. The mixing state was measured by observing the color of samples due to the reaction of NaOH and phenolphtalein.

II. Design of the new mixer for micromixing

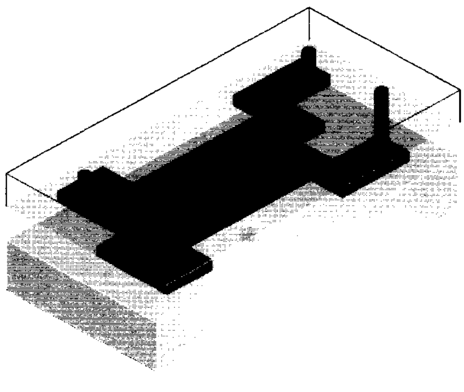
Monnier et al. reported a mechanism for micromixing generated by an ultrasonic wave [7]. In a small area, the deformation of an aggregate containing only species B was injected into an A-rich solution and mixed through several mixing processes.



(a) Cross section



(b) Components



(c) 3-dimenstional structure

그림 1. 제안된 믹서의 구조
Fig. 1. Schematic of the proposed mixer.

표 1. PMN-PT와 PZT의 주요 특성 비교
Table 1. Comparison of PMN-PT with PZT.

	PMN-PT	PZT
d_{33}(pC/N)	1561	500
k_{33}	0.992	0.7
k_t	0.621	0.49
ε_{33}^{T}	4991	1600

[d : piezoeletric constant,
k : electromechanical coupling factor,
ε : dielectric constant]

Considering the aforementioned, we propose a new mixer for micromixing as shown in Fig. 1. It includes a PMN-PT, a diaphragm, and a chamber. A PMN-PT with 0.15mm thickness was used to generate ultrasound waves. Table 1 shows that the PMN-PT has a higher piezoelectric constant than a PZT. This means the PMN-PT has a higher displacement than a PZT when they are driven by the same electric field. A diaphragm was used to isolate the PMN-PT from the fluids and as an acoustic matching layer to reduce acoustic loss due to the mismatch between the piezoelectric material and water. We used an epoxy material for the diaphragm, because it was attachable and had a proper acoustic impedance. Each sample was supplied into inlet 1 and inlet 2 and mixed in the chamber where the ultrasonic wave was radiated from the base, and expelled out through outlet 1 and outlet 2. We could remove unwanted bubbles contained in the samples by controlling the two outlets. The chamber was 5mm × 8mm ×3mm in volume. Each channel for inlets and outlets was 5mm wide and 60μm high. We manufactured a channel with acrylic material in the new mixer. Two fluids were placed into the upper and lower areas in the chamber such that the interface area between each fluid was parallel to the base. Mixing efficiency was enhanced because the ultrasonic wave was radiated vertically to the mixed interface and transverse agitation was generated.

Ⅲ. Experimental apparatus

The experimental apparatus for the performance test of the proposed mixer is presented in Fig. 2. It includes a signal generator, a power amplifier, the proposed mixer, a syringe pump, and a camcorder. The signal generator generated a 10Vp-p sinusoidal signal with 300kHz frequency. The power amplifier amplified the power of the output signal of the signal generator to 40Vp-p and drove the PMN-PT, which was attached under the mixing chamber. Samples were supplied to the chamber with a syringe pump at $20\mu\ell$/min flow rate in the mixer for micromixing. We obtained real time images using a camcorder (Sony DCR PC-330) to investigate the mixing state.

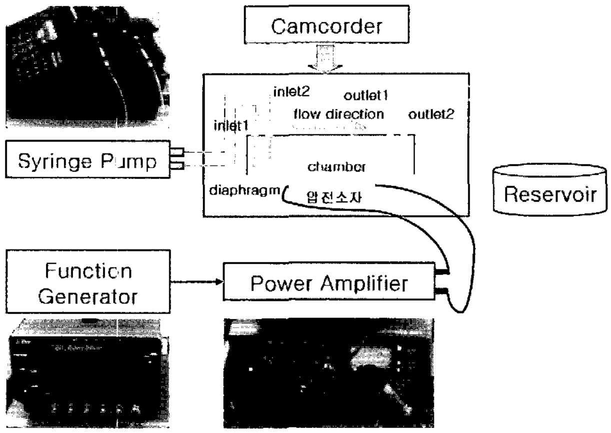


그림 2. 성능시험장치
Fig. 2. Performance test system.

Ⅳ. Experimental results

Phenolphthalein is colorless at the beginning and is used as a pH sensing material. The sample stays colorless if the pH of an examined sample is less than 8, but it becomes red if the pH is greater than 8. We measured the state of mixing by utilizing these properties. That is, the sample becomes red if two colorless samples are mixed properly otherwise it stays colorless. We used 0.3mol/ℓ NaOH and 0.1mol/ℓ phenolphthalein for the micromixing experiment. The two fluids were supplied at a $20\mu\ell$/min rate through the two inlets. During ultrasonic radiation, the mixed fluid in the chamber became dark red in Fig. 3, and we could thus confirm that it was mixed properly.

To investigate and quantify the mixed states in the chamber, we examined the intensity of gray images,

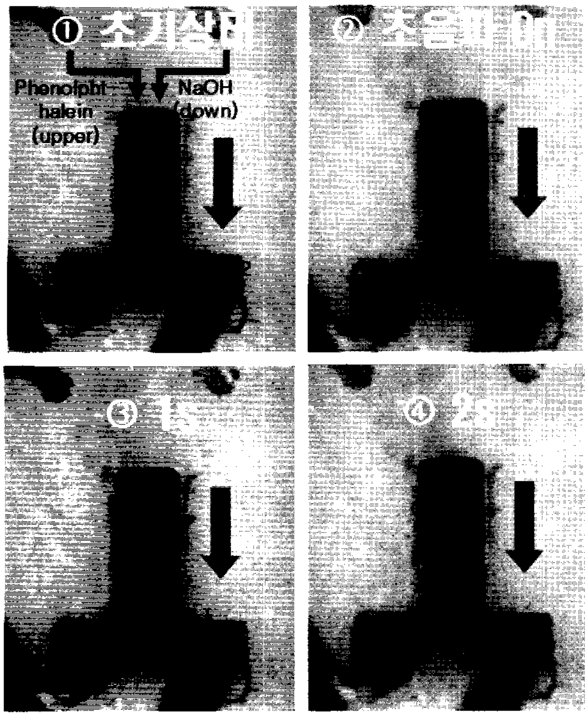
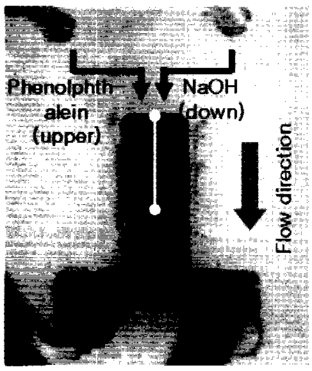
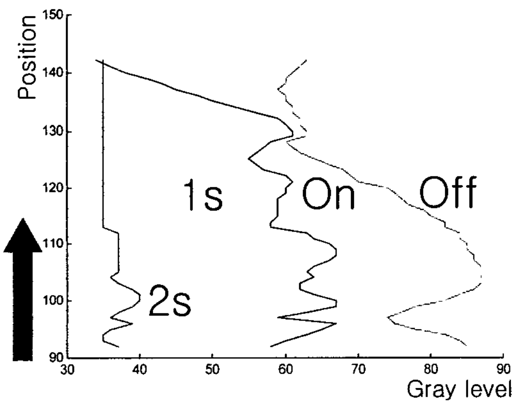


그림 3. 혼합실험 결과
Fig. 3. Results of the mixing experiment.



(a) Measuring position



(b) Gray level

그림 4. 혼합챔버 내에서 명암도 변화
Fig. 4. Variations of the gray level in the mixing chamber by ultrasonic radiation.

which were converted from the color images in Fig 3. Fig 4 shows mixed samples in the chamber have lower values of gray level when the radiation time by ultrasonic waves became longer. We see that less than 1s was needed to mix the two samples. This means the proposed mixer is effective in reducing the mixing time. We used a sinusoidal signal with 40Vp-p amplitude and 300kHz frequency. It is expected that a low driving voltage (40Vp-p) could contribute to miniaturization of Bio-MEMS devices that need a micromixer.

V. Conclusions

Because fluid in a microchannel has low Reynolds number values and eddy flow does not occur easily, samples in the mixing chamber are mixed only by diffusion. A lengthy period of time is required for proper mixing. Many studies on micromixers including active and the passive methods have been conducted to solve this problem. It has been reported that the most reliable and stable method among these methods is an active micromixer using ultrasonic waves. In this paper, we proposed a new mixer for micromixing wherein an ultrasonic wave with PMN-PT was emitted vertically on the boundary surface of two fluids. We confirmed the mixing state by observing colors of samples through the reaction of NaOH and phenolphthalein. The proposed micromixing method increases the contact area of the boundary surface where the two fluids meet and accelerates diffusion between the two fluids by ultrasonic radiation. Hence, it is possible to generate faster mixing. We could also reduce the driving voltage by using PMN-PT, which had a higher piezoelectric constant than PZT. We hope this study can contribute to the miniaturization and integration of microdevices for LOCs in the future.

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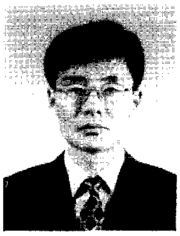

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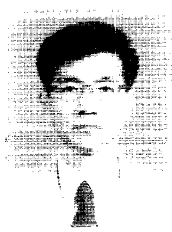

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