MEMS MIXER AS AN EXAMPLE OF A NOVEL CONSTRUCTION METHOD OF MICROFLUIDICS BY DISCRETE MICROPARTS

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ABSTRACT

This paper describes a novel approach to construct and/or functionalize a microfluidic chip with discrete microparts which are microfabricated enough small to place them in a microchannel. Preliminary demonstration was shown as a passive mixer. Microparts of several hundreds micrometers, were fabricated by double sides etching with ICP RIE. The parts were manually placed in a typical Y-shape PDMS microchannel. Fluorescence observation reveals that the constructed microfluidics has the same mixing ability as a fully silicon MEMS mixer. The configuration that is unable by the normal preassembled structure can be also fabricated.

KEYWORDS

micromixer, microreactor, μTAS, self-assembly

INTRODUCTION

A typical microfluidic chip consists of a microfabricated plate bonded to another plate [1]. Though some complicated and sophisticated 2D pattern can give a functionality [2] to the cannel, the addition of microstructure such as fins [3] (Fig. 1), pillars [4], and grooves [5, 6, 7] onto a limited part of an inside wall of the microchannel has a wide variety to functionalize the channel. Some microfluidics requires heterogeneous materials [8] or more complicated 3D structure [9-12]. However, the fabrication process of such a microstructure is complicated for silicon MEMS structure, and expensive to mold polymer, though preassembly nature of photolithography-based method and/or mold-based method have some advantages. Beads-packing [13, 14] is the only method to introduce microstructures into a channel (Fig. 2). On the other hand, we have recently reported a passive silicon MEMS mixer, that rearrange a two-layered laminar flow into a four-layered flow [3] (Fig. 3). As shown in Fig. 1, the structure of the mixer has a horizontal plate at a half depth of the channel. Requirement of double-side etching to form the plate constrains the whole chip design.

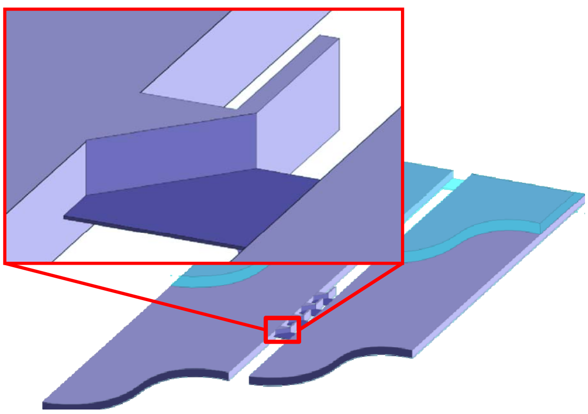

Figure 1: Schematic representation of a passive Si MEMS Mixer in the previous report [3] bonded to glass plates.

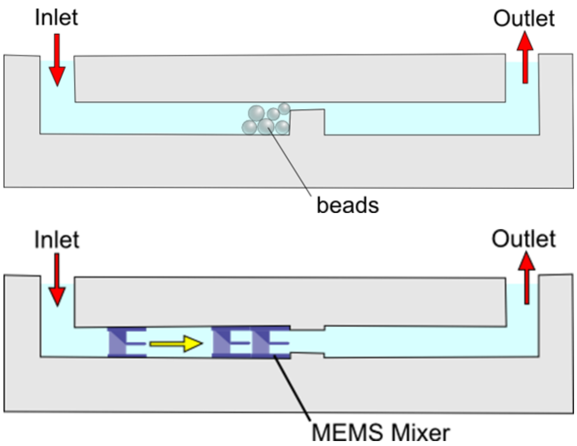

Figure 2: Schematic representations of the chip configuration. Top shows typical beads-packing, and the bottom shows the configuration in this research.

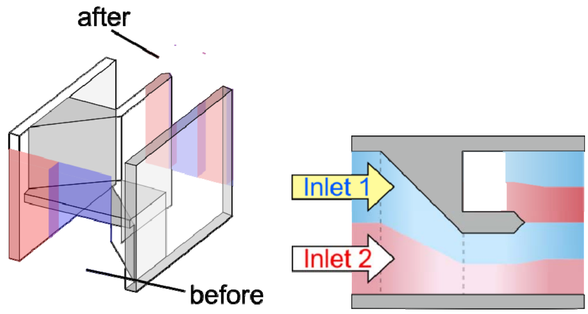

Figure 3: Mixing process by the Si MEMS mixer. Two liquid layers are divided and rearranged into 4 layers from 2 by the mixer

In this research, we propose a novel approach to construct and/or functionalize a microfluidic chip with discrete microparts [15] which are microfabricated enough small to place them in a microchannel (Fig. 2). Combination of a cheap long microchannel and microparts may enhance the productivity as already done by beads-packing method. As the first example, the passive silicon MEMS mixer of the same inner dimension but once clipped from a Si wafer as a discrete microparts and placed in a PDMS microchannel.

EXPERIMENTAL

Fig. 4 shows a process overview. The area around a mixer was also etched by 3 times of DRIE contained in the mixer fabrication process to fabricate a discrete mixer. The

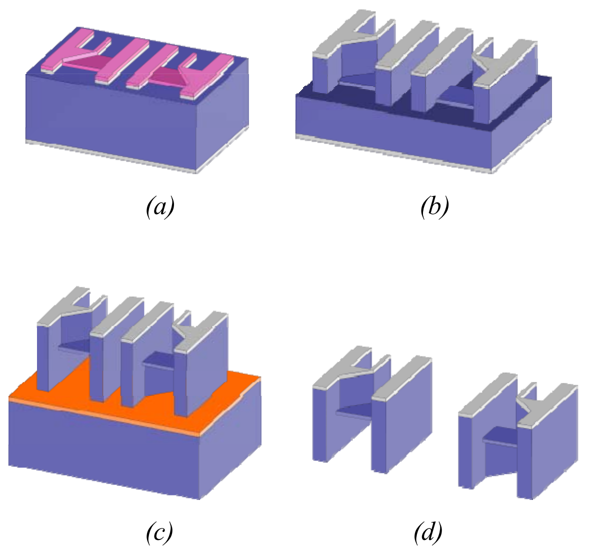

Figure 4: Fabrication process of the discrete Si MEMS micromixer. Photoresist and SiO_2 were used to fabricate partition plate into the micro mixer.Front side of Si was patterned (a) and etched by two-step DRIE (b).Then the wafer was glued to another plate),and back side DRIE divided the parts from the wafer (c), and finally released from the plate (d).

front-side of Si wafer (300 µm thick with 1 µm SiO_2) was etched by twice DRIE to make a step of partition plate into the micro mixer. The Si wafer glued to another plate with cool grease to prevent micromixer from dropping in the process chamber of DRIE. The backside of Si wafer was etched by once DRIE to form a discrete micromixer (L400 × W300 × D300 µm) on the glue, and soaked into solvent to release them.

The mold which turns into a model of a channel in the same fabrication process as mixer was also produced. Because the microchannel depth is 300 µm and both the size of it and the mixers have to be the same. Two kinds of mold were fabricated. One was a typical Y-shape form and the other was a Y-shape with an additional inlet downstream of Y-shape. The additional inlet was designed to be a half height branch at an angle of 45 degrees to flow only into the upper layer of channel (Fig. 5). PDMS microchannel was fabricated with these molds. The fabricated mold was bonded to a flat PDMS plate with an assist of O_2 plasma. PDMS prepolymer was poured onto the mold and baked 2h on a hotplate at 80 degree C. Finally, manual operation integrated the fabricated micromixer into PDMS microchannel (W300 × D300 µm).

Two methods were used for how to incorporate a mixer with microchannel. The 1st method is incorporates a mixer with microchannel so that it may become the same form as the preassembly type. The 2nd method is rotates 90 degrees and incorporates a mixer. In order to confirm the mixing ability of the device incorporating a mixer, the experiment which used the fluorescent dye (FITC) was flowed. Ethanol and the ethanol with FITC were used for an experiment. The flow velocity was the same (100µl/min) as for the preassembled type of the same dimension to compare the device. Moreover, in order to

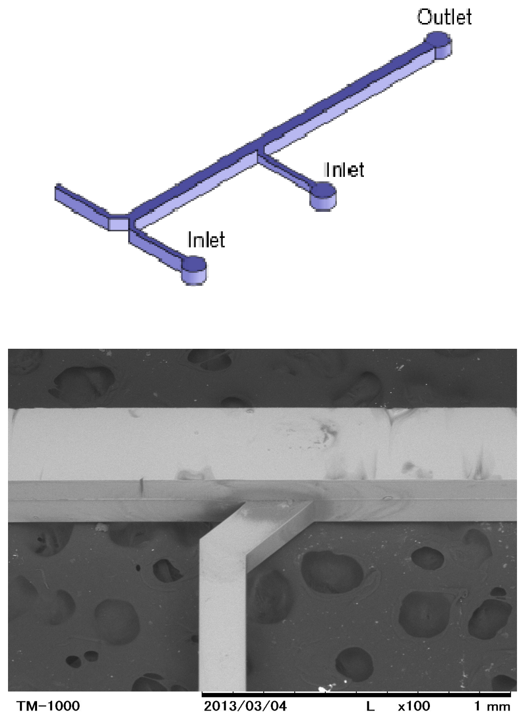

Figure 5: The microchannel for the mixing observation of the depth direction. In order to pour partially into upper layer from the middle of Y-shape microchannel, a mold was fabricated so that the inlet has only a half height.

investigate the performance of the device which rotated 90 degrees, mixing condition of the depth direction was observed by a confocal microscope (TCS-STED-CW, Leica Microsystems).

RESULT AND DISCUSSION

According to our first estimation, 800 set of MEMS mixers can be designed on a 4 inch wafer, while only 30 chips can be designed. The yield actually became about 30% because an etching rate of DRIE in the wafer side had a considerable dispersion. But these were larger than the amount of products of the microfluidic chip from Si wafer. Fig. 6 shows a SEM view of the fabricated discrete Si MEMS mixer and the PDMS microchannel with an additional inlet. Ethanol and ethanol with FITC were flowed to form two layered laminar flow in the PDMS microchannel. Fig. 7 shows a fluorescence view around the micromixer in the channel, and Fig. 8 shows fluorescence intensity distribution. Both mixers made the stream of '10' distribution rearranged to '1010' distribution. The results show that the discrete MEMS mixer has the same mixing ability as the preassembled type of the same dimension.

Fig. 9 shows a simple example the usefulness of the proposed method with the complicated configuration that is unable to form preassembled fabrication method. Though the parts are placed manually in this research, resulting total chip fabrication cost is still expensive, this method becomes cost effective with the combination of a low cost assembly method.

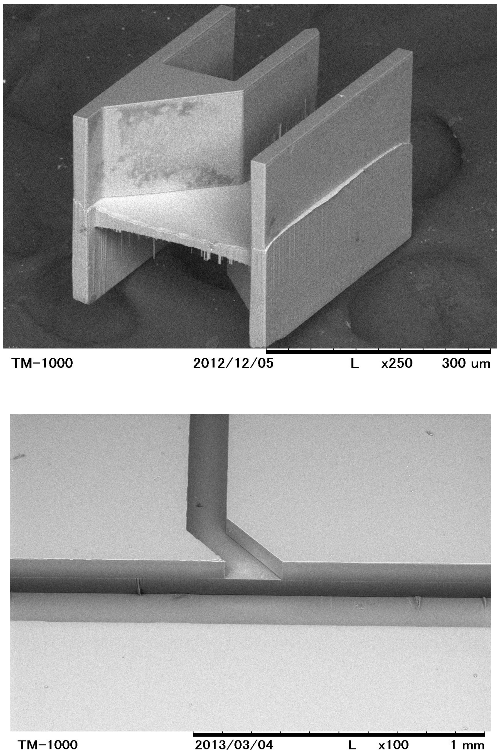

Figure 6: SEM view of the fabricated discrete micromixer and Y-shape microchannel with the additional inlet.

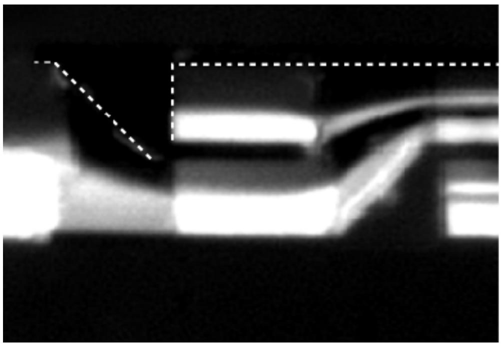

Figure 7: Fluorescence view of the mixing area of the chip. Fluorescent dye were flowed from left to right. Black area is the Si MEMS microstructure

Fig. 10 shows the fluid simulations of device which was incorporated the mixer rotated 90 degrees and the result of fluorescence observation on the area around a mixer. Ethanol and ethanol with FITC were flowed from the one side of Y-shape inlet and additional inlet. It is expected that mixing to the depth direction is seen only at the inlet side because ethanol with FITC which was flowed from the additional inlet and stayed to form a two phase laminar flow in the microchannel. According to a simple fluid simulation, if the channel of this research is used, the liquids by the side of an inlet will be divided in the depth direction. The result of observation, the fluorescence of the area around a mixer showed almost the same tendency as a simulation. For example, in (e) and (f) of Fig 10, fluorescence could observe not only upper layer but also lower layer part same as simulation result. Fluorescence

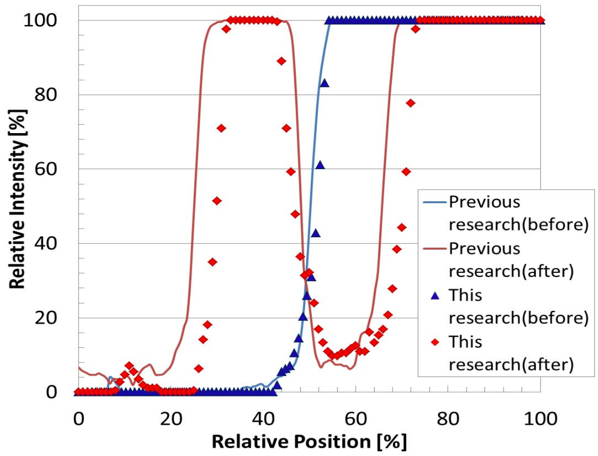

Figure 8: Distributions of fluorescence intensity across the channel. Solid lines shows the results from the previous preassembled chip, and dotted plots shows the results from this research. Blues are before mixing, and reds are after.

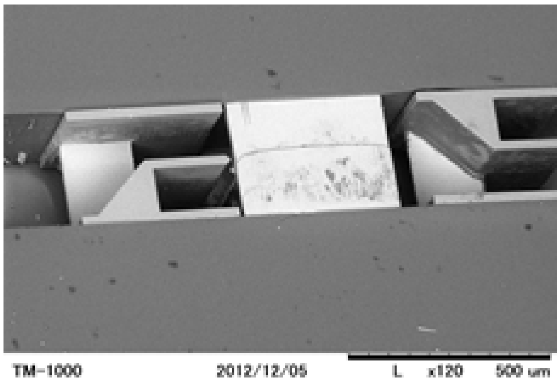

Figure 9: Special configuration of the 3 microstructures. The center microparts was placed with 90 degree rotation.

observed in the top-middle of Fig.10(g) shows a gap between the fabricated micromixer and the channel. This may due to the fabrication error, and improvement of the etching rate dispersion in DRIE steps may avoid such a problem. These results show that we could fabricate devices which have impossible configuration in preassembly method.

CONCLUSION

This research proposed the novel construction method of microfluidics by discrete fabrication microparts assembled to the microchannel. The proposed method enables us to fabricate more complicated and high level microfluidic chip than the conventional configuration, or preassembled structure. In order to verify possibility of this research, mixing ability of microfluidic chip which fabricated by incorporating discrete MEMS mixer with microchannel was confirmed. Moreover, possible configuration only assembly structure was constructed by changing the method of arrangement of the MEMS mixer. Fluorescence observation revealed that discrete type had the same mixing ability as preassembled type. Furthermore, device which was incorporated the mixer

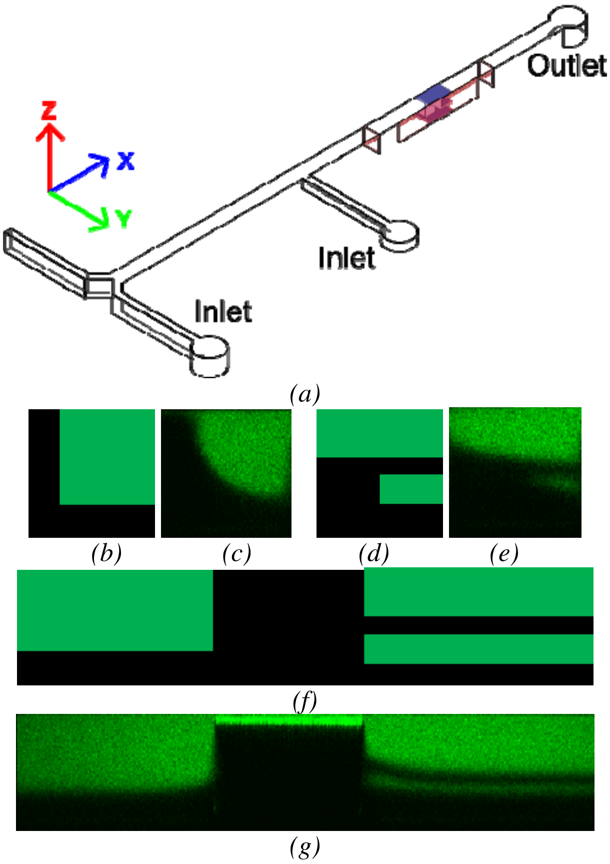

Figure 10: Mixing process of micromixer with 90 degree rotation. (a) shows observed microchannel which was incorporated micromixer. These show the fluid simulations and the results of fluorescence observation of (b) - (e) YZ plane, (f) and (g) XZ plane. (b), (d) and (f) show simulation, (c), (e), (g) show result of fluorescence observation.

rotated 90 degrees. The configuration is unable to establish by preassemble method. These results show that the possibility to construct a complicated and high level microfluidic chip. Unfortunately, the resulting total chip fabrication cost is still more expensive than the conventional manufacture method because the microparts were placed manually in this research. The combination of a low cost assembly method, such as self-assembly method enables novel fabrication method of microfluidic.

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