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Performance and Effective Method of Experimenting Micromixer Using Finished smooth glasses and Cohesive Tape

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Abstract

Micromixer has been drawing upon various branches of engineering science and allied areas within biology and biomedicine. In the present study, an easy and fast fabrication method on hydrophilic micromixer using Optically Clear Adhesive (OCA) double-sided tape together with glass is proposed. Different experiments on types of planar hydrophilic micormixers with baffle structures are designed for hydrophillic microchannel. Flow is driven by capillary action using surface tension and flow tests are carried out to show that the double-sided OCA tape-glass micromixer can achieve the mixing result of 71% in gray level image analysis.

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Keywords: *Capillary, chip, hydrophilic, microfluidic, micromixer, mixing, OCA.*

1. Introduction

Microfluidic systems have shown a wide application to biomedical science and are well-received in medical examination. In some special cases, micromixers have demonstrated promising practices to the area of bio-technology field such as application of RNA/DNA and PCR amplification [1, 2]. In general, micromixers can be featured in two categories, namely the active micromixers and passive micromixers. An active mixer required external powers to effect the mixing of fluids [3, 4], while a passive mixer can only handle the fluid by splitting and recombining the stream in the device [5, 6, 7, 8].

There are many ways to produce the microchannels in the experiment and it is by virtue of the use of MEMS devices. For example, the mechanism of pumping the fluids in MEMS devices is developed and shown in [9] where the authors undertake the work to provide the best solution in the application of micropumping. Other progress has made the use the chemical and biological knowledge [10] which is focused on the development of the pumping technique and controling of fluid delivery. The establishments of the pumping technique are very important in applications such as thermal, light, magnetic and electrical mechanisms, and micropumps such as electroosmotic, electrophoretic, opto-electrowetting, electrochemical, optically-driven, and gravity-driven pumps all use the mechanism of electro- or kinetically-driven continuous flow to drive fluids in the MEMS where three different kinds of miscible solutions (phosphate-buffered solution, gold nanocolloids and 20% glycerol), with Rhodamine 6G aqueous solution, were used as sample fluids [11]. In addition, there is a fabrication method for single glass microchannels which uses conventional photolithographic and chemical etching process [12], and the fabrication of glass chips by using electrophoresis mechanism with capillary phenomenon is shown in [13]. It is well known that the device is produced by glass substrates using thermal bonding method. Moreover, for the PDMS microchannels using SU-8/PMMA moldings and polystyrene substrate, the microfabrication method was reported in [14]. In addition, the method of using O_2 plasma to change the PDMS characteristics and creating different profiles of microchannels was shown in [15]. In recent years, the use of negative photoresist JSR and PMMA polymer as a substrate is employed for the formation of microchannel structures [16] and an interesting approach that integrates the method of photoresist and soft lithography with circular microchannels was proposed in [17].

The present study introduces an fast yet easy experiment in fabricating hydrophilic micromixers. We do the fabrication by using the double-sided optically clear cohesive tape together with glass substrates and laser machining technique. The double-sided cohesive tape is of OCA8187 from 3M Company, which has high strength of adhesion to different glass surfaces with weatherable and water-resistant ability. We would like to combine the finished hydrophilic glass substrates and engrave microchannels to drive the fluid streams using surface tension. The finished micromixer is designed as Y-shaped

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with baffled structures extended for 18 mm long, and the width of channel is 600μm with the width of the baffle to the channel wall as 150μm. Water-assisted CO_2 laser machining is applied to cool down the glasses during the manufacturing process and cohesive tape-glass microchannel pattern was carved out with bounded glasses.

It is shown in literature that microchannel with PDMS requires a length of 15-20 mm to achieve an uniform mixing [18, 19], but it is found the channel suffers low transport velocity for liquids and poor hydrophobic recovery for substrates [20, 21]. To fix the situation, a Liquid Crystal Polymer (LCP) with glass chip was introduced to improve the hydrophobic recovery property but still shows difficulty in fabrication when using CO2 laser machining [22]. As far as we understand, most microchannels can be done with glass or PDMS materials for mixing purpose, but it still shows the fact that the PDMS with glass is unstable and can suffers poor thermal bonding. Out main idea of using tape-glass microchannel materials stays with the advantage properties of the hydrophilic, and thermal bonding of the material. The cohesive tape-glass features good hydrophilic characteristic and require less complexity of fabrication process. The present paper aims to introduce a novel process of fabrication tape-glass mixromixer with hydrophilicity.

We aimed to place a number of baffles periodically in the microchannels in an alternating fashion. The chip for baffle structures and that without baffles are shown in Fig. 4 and Fig. 5. The baffle structures in microchannel can be seen in Fig. 7 and Fig. 8. Notice that the baffle gap is fixed at 90μm while baffle space was fixed at 150μm. Fig. 8 shows the details of the chip with baffle space and gap. The baffles in microchannel will allow interfacial contacts for liquids at low Reynolds number and we conducted a series of flow tests to study the mixing performance. The Reynolds number in the capillary channel is less than around 0.2 and the tape-glasses structure has the property of hydrophilic stability. It is not only an easy manufacturing process but also avoids annoying etching and depositing process.

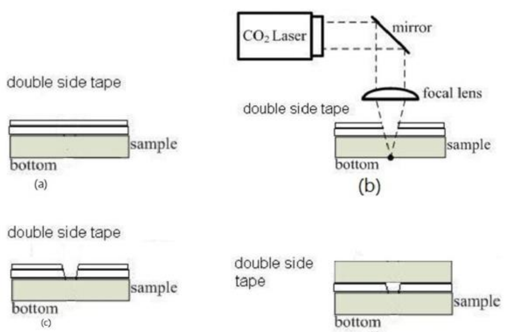

Figure1. Fabrication procedure for Optically Clear Adhesive (OCA) double-sided tape-glass microchannel

2. Experimental Procedures

Our experiment adopted tape of 3M, OCA8187, with high strength of adhesion and water resistance. It is also humidity- and UV light-resistant when applied on optical device material.

We use laser machine to fabricate the microchanel with cohesive tape and glasses. The glass is a microscope slide (FEA) with size of 1”× 3”and thickness of 1-1.2 mm. By cleansing with isopropyl alcohol, we are able to wash substrate with Deionized (DI) water and dried it with compressed-air gun. Then we can attach the double-sided OCA cohesive tape onto the microscope slide and tear off the protective layer during the process (Fig. 1(a)). The double-sided OCA tape has high cohesion and durability and easy application to different surfaces. Moreover, the laser power of 5 Watts and scan speed of 11.4 cm/s were used to drill holes with carved channel pattern (Fig. 1(b)). The water-assisted CO_2 laser is used to cool down the glass during the carving process. Finally, we bond the cohesive tape-glass pattern with another substrate by matching the inlet and outlet (Fig. 1(c), Fig. 1(d)).

As from Fig. 1(d), the glass slides were bonded on top and bottom sides of surfaces with cohesive tape for carving microchannels. Therefore the bonding and contacting surfaces of microchannel are on the glass with OCA cohesive tape attached on the left and right contacting phase. Notice that the double-sided cohesive tape has high durability and water resistance, which make tape-glass microchannel hydrophilic to be able to drive fluids on the substrate. Fig. 2(a) shows the contact angle of DI water on PDMS for comparison, and Fig. 2(b) shows the contact angle of DI water on OCA-glass slide. The flow chart of fabrication procedure is shown in Fig. 3.

As the baffled structure in microchannel is considered, we use the software CorelDRAW(R) 12 to draw the channel pattern and laser machining to carve the channel in micro-scale size. In our experiments, the baffled structure and microchannel was set with length of 1800 μm and width of 600 μm. Moreover, the space between the baffled channel wall was 150 μm and the depth was set as 175 μm. Fig. 4 shows the graph of micromixer without baffle structure, while Fig. 5 demonstrates the graph of micromixer with baffle structure. The finished work of double-sided cohesive tape-glass micromixer is shown in Fig. 6.

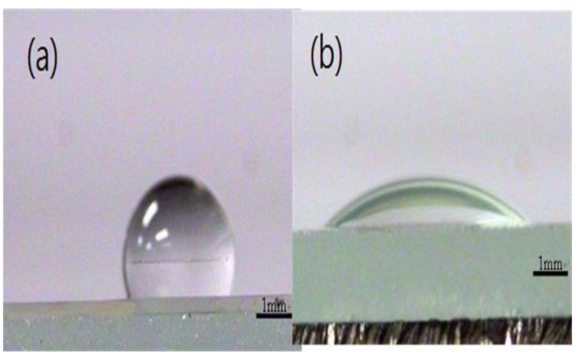

Figure2. Contact angle of DI water (5μl) on material surface; (a) PDMS substrate; (b) OCA-glass slide..

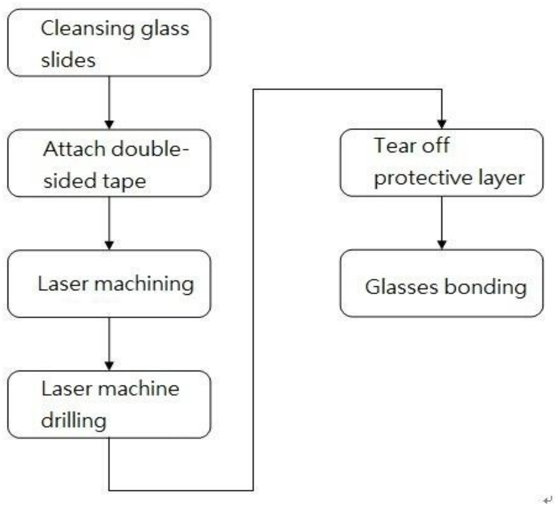

Figure3. Flow chart of fabrication procedure for double-sided tape and glass microchannel.

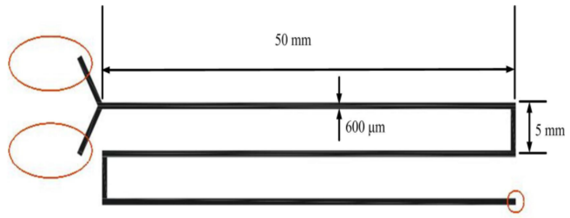

Figure 4. Schematic diagram of CorelDRAW graph for OCA tape-glass micromixer without baffle structure..

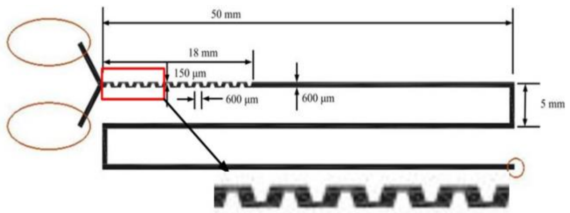

Figure 5. Schematic diagram of CorelDRAW graph for OCA tape-glass micromixer with baffle structure.

3. Governing Equations and Theory

The physics for capillary-driven flow in the microchannel relies on the driving force Δ*p*, and the Laplace-Young equation as follows [23]:

$$\Delta p = \frac{2\sigma(h+w)\cos\theta}{wh}, \quad (1)$$

where Δ*p* is the pressure drop across the interface, σ the surface tension of the fluid, θ is the contact angle, *w* the width of the microchannel, and *h* is the height of the microchannel. Notice that if the contact angle is less than 90^0, then the driving force across the interface will be positive and the fluid will be driven along the channel. As the width of channel is much larger than its height, the driving force will be expressed as the following form:

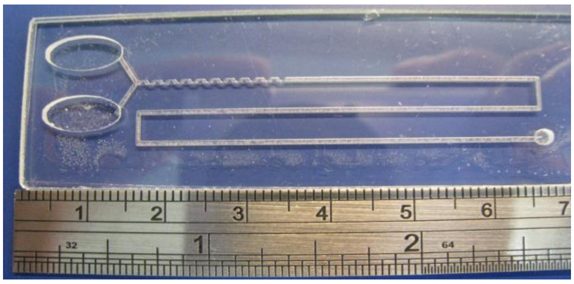

Figure 6. The finished work of double-sided OCA tape-glass baffled micromixer..

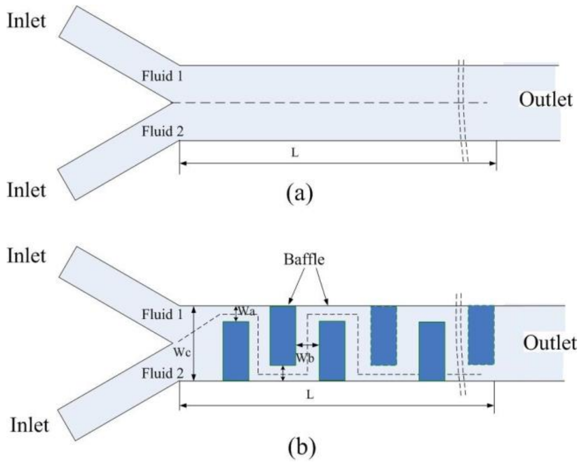

Figure7. Detailed schematic diagram of microchannel with baffles..

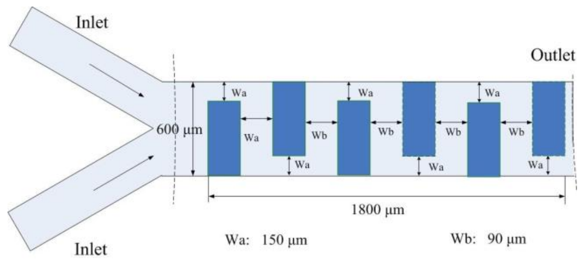

Figure 8. Flow direction and design of baffles for microchannel.

$$\Delta p = \frac{2\sigma\cos\theta}{h}. \quad (2)$$

Our work focuses on the rectangular microchannel with its geometric dimension w>>d, which it will make the surface and the capability of capillary action to be activated to drive the fluids in the microchannel. We also note that in such a small dimension, the capillary action will drag the liquid where the adhesion of liquid molecules will attach onto the surface of glass substrates.

In our idea, the use of the OCA cohesive tape on glasses provides the wetting stability in microchannels. In theoretical analysis, since the OCA tape- microchannels is small in dimension to allow the pressure drop across the air/liquid meniscus and will be assumed to have the following expression [24]:

$$\Delta p = \frac{2\sigma w \cos\theta_1 + 2\sigma h \cos\theta_2}{wh}, \quad (3)$$

where θ_1 is the contact angle of both the upper and bottom walls, θ_2 is the contact angle for left and right walls and *h* the height of the microchannel. Moreover, by taking the depth of the channel into account, the factor to control the fluid behaviour in the microchannel can be expressed as follows [25]:

$$Q = \frac{1}{\eta}\frac{\Delta p}{R_F}, \quad (4)$$

where η is the viscosity of the liquid, Δp the difference in pressure inside and in front of the liquid, *Q* the flow rate and R_F is the flow resistance of geometry with the following [25]

$$R_F = \frac{1}{12\left(1+\frac{5h}{6w}\right)\frac{hwR^2_H}{L}}. \quad (5)$$

Here *w* is the width of channel, *h* is the depth of channel, *L* is the length of channel, $R_H=hw/(h+w)$ is the hydraulic radius for rectangular channel. By Eq. (5), we also notice that the longer the channel length, the bigger the flow resistance. Detailed mechanism of the physics and dynamics of capillary flow, including the the governing equations of the capillary flow are represented as follows:

$$\nabla \cdot V = 0, \quad (6)$$

$$\rho V \cdot (\nabla \cdot V) = -\nabla P + \mu \nabla^2 V, \quad (7)$$

$$\frac{\partial F}{\partial t} + \nabla \cdot VF = 0, \quad (8)$$

where *V* is the velocity, ρ the density of fluid, *P* the pressure, μ the viscosity and *F* is the liquid volume fraction. The above equations will give the physics and movement of meniscus of capillary flow in a microchannel and numerical calculation will require the nonlinear coupling equations (6)-(8).

4. Results and Discussions

The present study addresses a special method of fabrication for hydrophilic microchannel using the double-sided cohesive tape with glasses. We carried out the procedure for microchannels with baffle structures. The fabrication procedure is performed through the laser machining and image capture device and the flow behaviour is captured by digital CCD optical microscope (MORITEX MLZ-07545). The mixing results of the cohesive tape-glass mixer without baffles are shown in Fig. 9, while the mixing behaviour for micromixer with baffle structure is illustrated in Fig. 10. It is seen that the mixing performance can be significantly improved if one adds the baffle structure in the channel.

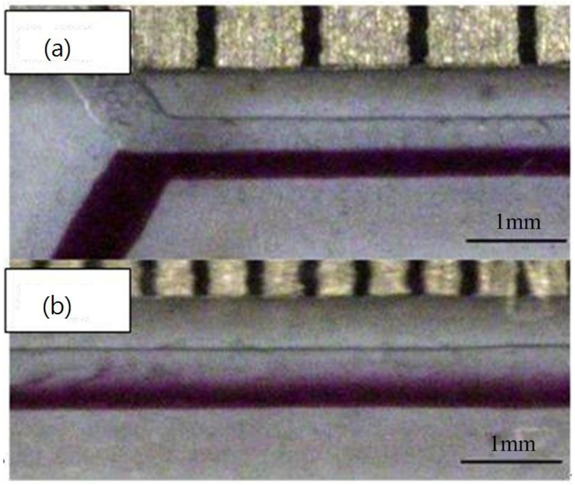

Figure 9. Mixing tests for OCA double-sided tape-glass straight microchannel; (a) upstream area; (b) downstream area.

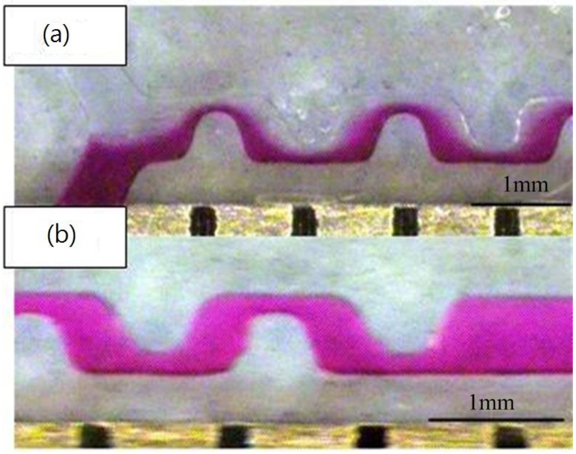

Figure 10. Mixing tests for OCA double-sided tape-glass baffled microchannel; (a) upstream area; (b) downstream area.

In order to quantity the degree of mixing, the mixing efficiency is calculated by the following formula:

$$M = 1 - \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{n_i - \bar{n}}{\bar{n}}\right)^2}, \quad (9)$$

where *M* is the mixing efficiency, *n* is the total number of sampling points, n_i the mole fraction over the whole cross section at the outlet of the micromixer and $\bar{n}$ the average mole fraction. Mixing efficiency is calculated from 0.00 (0% mixing) to 1.00 (100% mixing).

We calculate the mixing results at the inlet-structure (entrance) and outlet-structure (exit) of the baffled channel of Y-shaped chip. Our idea was focused on the mixing behaviour at in- and out- of the baffled structure as well as its mixing results.

The mixing efficiency for OCA double-sided tape-glass micromixer without baffle is recorded as 19% at the entrance and 30% along the length of 18mm downstream, while the mixing efficiency for micromixer with baffles at the same condition is recorded as 21% in the inlet-structure, and 71% at the outlet (Fig. 9, Fig. 10 and Table 1).

It is seen that the mixing is improved because the baffles help increase the contacting areas for fluid streams. Moreover from Fig. 11, we see that it is likely to generate a bubble at the corner of the channel during the mixing experiment. Such a rare phenomenon is found due to the use of special material and fabrication process. However, we still point out that the most advantage for tape-glass microchannel is that it is easy to fabricate, fast-adapting and cost-saving for lab procedure, and convenient for quick integration of chip.

With careful investigation in the process, the tape-glass microchannel is as hydrophilic stable as the JSR-glass, PMMA or PDMS microchannels. This shows that the tape-glass structure can easily achieve a long term capillary-driven characteristic as other materials.

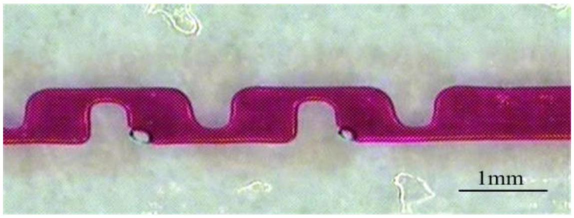

Figure 11. The air bubble in the OCA tape-glass microchannel.

We also test and compare the capillary flow in straight PDMS microchannels using conventionnal photolithography, molding and oxygen plasma bonding. These PDMS materials were stored at different storing times after fabrication, namely 12 min, 25min and 50min and flow were tested out with DI water and is shown in Fig. 12. It is seen that PDMS microchannel of storing time of 12 min can have the meniscus interface move down the channel at an elapsed time of 4.6 sec. For PDMS of storing time of 25 min, the flow time will increase with decreasing moving velocity. The lowest moving velocity of meniscus interface was observed at the storing time of 50 min, which takes around 18 sec to run through the channel. Experimental results show that traditional PDMS chip is easily affected by the storing time of the finished work, which not only destroys the hydrophilic feature but also suffers inefficient fabrication process.

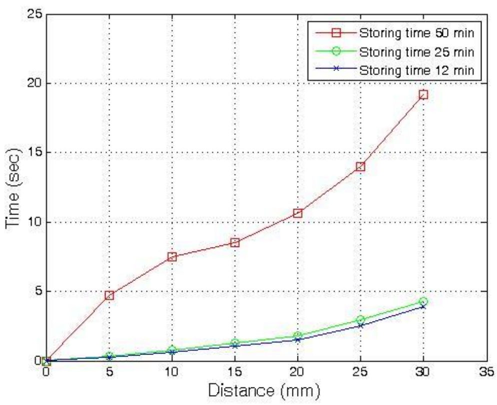

Figure 11. Relationship between the fluid traveling time and distance of PDMS channel at different storing time.

By comparison, the same capillary-driven tests of fluids were carried out on straight tape-glass channels. Fig. 13 recorded the test results of the OCA tape-glass microchannels at different storing time. It is shown that at storing time of 0 day, the meniscus interface moves downstream to the channel at an elapsed time of 3.6 sec, while for the tape-glass of storing time of 45 days takes the elapsed time as same as those above. This shows that our finished work is made from intrinsic hydrophilic materials.

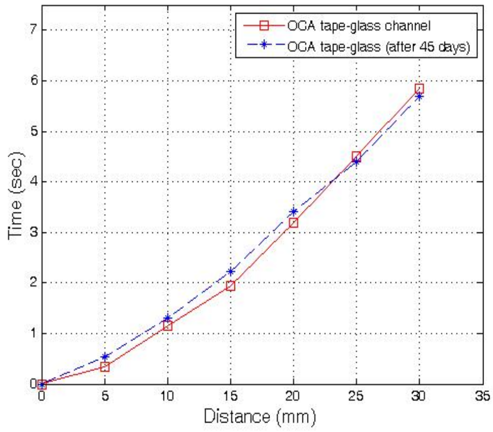

Figure 13. Relationship between the fluid traveling time and distance of OCA tape-glass channel at different storing time.

the present paper addresses the fabrication method of glass-tape chip with baffle structures installed so as to bring an interesting experiment for the capillary-driven micromixer. Here two fluids of ethanol marked by 5 wt% deep blue ink (Quink Co.) and DI water were used to demonstrate the fluid mixing results. The baffle structure indeed helps improve the mixing results at the exit of the downstream area.

The related data regarding the mixing performance are recorded in Table 1 where we have listed the mixing efficiency for tape-glass micromixer. From the results we see the mixing efficiency at entrance of baffled structure is only 21% while 71% is obtained at exit of the baffled structure. We conclude that the mixing results of tape-glass microchannel is improved due to its implemented baffle structure and easy fabrication, cost-saving process compared to the PMMA chips [14, 15, 16, 17] and PDMS chips [18, 19]. Here we point out that smaller baffle spaces will also increase the interfacial contact areas and decrease the diffusive distances in length.

Table 1. Mixing efficiency test for OCA double-sided adhesive tape at inlet- and outlet-structures

Baffle/Mixing	Inlet-structure	Outlet-structure
No Baffles	19%	30%
Baffle structures	21%	71%

.

5. Conclusion

The tape-glass microchannel is simple and easy in fabrication and takes the advantages of cost-saving feature in the procedure. The mixing result (71%) is acceptable when considering the efficiency of chip manufacturing.

We also compare the capillary tape-glass chip with conventional PDMS microchannel to obtain a relatively acceptable mixing efficiency and performance. We note that there are some reports for the applications of PDMS microchannels but the introduction of double-sided cohesive tape microchannel on glass is still of interest in the applications. In particular, we implemented a number of baffle structures in the channels and studied the mixing performance. Our experiment shows the idea of tape-glass hydrophilic structure not only simple in fabrication but also the cost-saving in product manufacturing. Our design of the chip with baffle gap of 90μm and baffle space of 150 μm shows a well-established structure for effective mixing to reach 71% in gray level image analysis. The advantage of hydrophilic micromixer design in terms of the use of double-sided cohesive tape has its values in not only providing with an interesting idea of capillary micromixer but also emphasizing an important fabrication method in Engineering apart from the widely-adopted PDMS hydrophilic chips. Our experiment shows that the double-sided tape-glass micromixer with baffle structure is very suitable in generating capillary flows and for achieving good mixing results.

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