THREE-DIMENSIONAL HYDRODYNAMIC FOCUSING OVER A WIDE REYNOLDS NUMBER RANGE USING A TWO-LAYER MICROFLUIDIC DESIGN

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ABSTRACT

In this paper, we describe a microfluidic device with a novel two-layer microchannel structure to enable three-dimensional (3D) hydrodynamic focusing. Numerical results indicate that the device works reliably over a wide range of Reynolds numbers (*Re*). These results are confirmed using confocal laser scanning microscopy. The structure can be easily experimentally integrated into microfluidic systems with an optical module for cell/particle bioassay.

KEYWORDS: hydrodynamic focusing, Reynolds Number, microfluidics

INTRODUCTION

Hydrodynamic focusing is an important flow-control technique, which has been employed in a number of applications, such as microchip flow cytometry and laminar mixers to study kinetics of enzymatic reactions. Nevertheless, traditional planar microchannel networks generally only facilitate a two-dimensional focusing by horizontally compressing the sample stream from both sides. Cells or particles in the focused sample stream are still spread out in the vertical direction, however. Therefore, there is great interest in developing a microfluidic device that is capable of focusing the sample stream in both, the horizontal and the vertical direction. Up to now, only a few 3D focusing systems were reported. Often, these approaches require tedious fabrication processes [1, 2] and only work well within a limited *Re* range (<5*)*. Recently, Mao et al. [3] developed a “microfluidic drifting” technique to enable 3D focusing with a single-layer planar microfluidic device. While it is much easier to fabricate, it only works well at rather high *Re* (>50). Here, we present a simple two-layer channel structure for 3D focusing over a wide *Re* range (>0-25).

EXPERIMENTAL

For evaluation, a PMMA prototype was fabricated using micromilling [4]. Figure 1 shows the details of the geometry of the proposed 3D focusing system and the fabricated PMMA chip along with a chip holder providing fluid connections. Figure 1a shows the schematic diagram of the 3D focusing system, where ‘B’ denotes the sample stream and ‘A’, ‘C’ and ‘D’ denote the sheathing flows. Two smaller channels are fabricated in the lower layer (B and C, 200×200 μm) and two larger channels (A and D, 400×400 μm) are fabricated in the upper layer (the relatively large dimensions are imposed by the fabrication method). After milling, the two layers were bonded thermally (Figure 1b).

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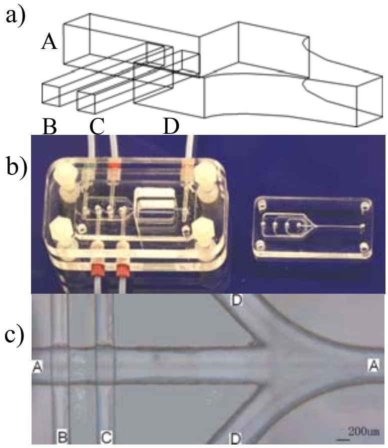

Figure 1. a) Schematic diagram showing a two-layer structure for 3D focusing, b) Photograph of the microfluidic device and chip holder fabricated by micromilling, and c) Magnified image of the main functional area.

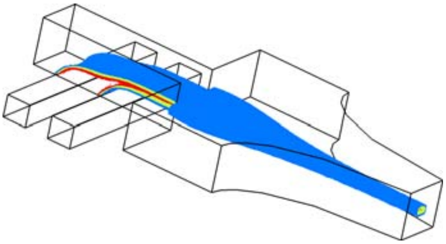

Figure 2. A concentration isosurface of the focused stream obtained by numerical simulation for the proposed 3D architecture, operating at a Reynolds number of 20. Here $Q_A = Q_B = Q_C = Q_D = 576$ µl/hr.

RESULTS AND DISCUSSION

Figure 2 presents a COMSOL 3.4 finite element simulation for the proposed architecture indicating successful 3D focusing. The sample stream is first vertically focused into a narrow stream, and then horizontally shaped to a rectangular cross-section. Confocal laser scanning microscopy is employed to experimentally confirm these simulation results. Figure 3 shows the comparison of the simulation result and an experimental image obtained by confocal laser scanning microscopy of the cross-sectional profile in the main channel ‘A’ between channels ‘C’ and ‘D’. Excellent agreement is evident between them.

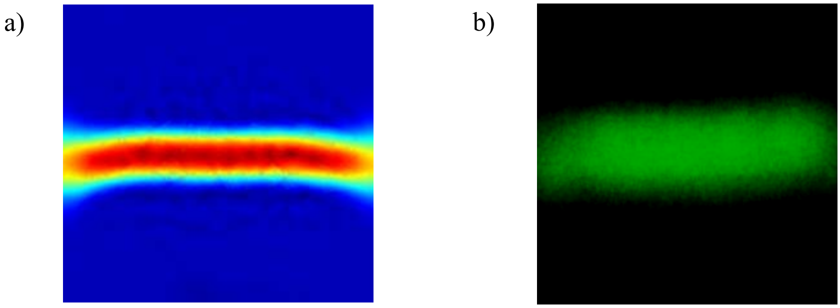

Figure 3. a) Numerical simulation of the cross-sectional concentration profile of the focused stream in the main channel 'A' between channels 'C' and 'D', and b) experimental image performed under the same flow conditions using confocal laser scanning microscopy.

Finally, Figure 4 shows the simulation result and experimental image of the cross-sectional profile of the focused stream in the main channel ‘A’ after the intersection of channels ‘A’ and ‘D’. Excellent agreement is evident between them as well. Similar results have been obtained for lower *Re* (down to 0.5).

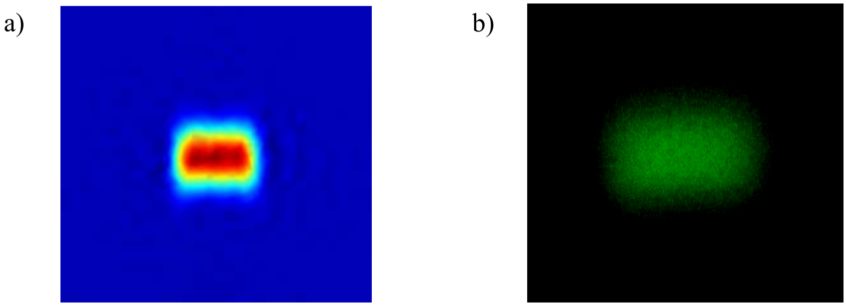

Figure 4. a) Numerical simulation of the cross-sectional profile of the focused stream in the main channel 'A' after the intersection of channels 'A' and 'D', and b) experimental image performed under the same flow conditions by confocal laser scanning microscopy.

CONCLUSIONS

These results demonstrate that the two-layer structure facilitates 3D hydrodynamic focusing. At the moment, a standard MEMS-based fabrication procedure is being developed allowing the proposed geometry to be realized in a SU-8 layer with integrated optical waveguides and a PDMS layer transferred from SU-8 master molds, using a single photolithographic step. The chips will be used for detection of scattered light from sub-micrometer particles in biochemical assays.

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