THREE-DIMENSIONAL HYDRODYNAMIC FOCUSING ACHIEVED BY A SINGLE CHANNEL LAYER, SINGLE SHEATH-FLOW INLET MICROFLUIDIC DEVICE

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ABSTRACT

This paper reports a microfluidic device capable of achieving three-dimensional (3D) hydrodynamic focusing with a single channel layer and single sheath-flow inlet design. The sheath flow is introduced in the vertical direction flows around the core stream in the horizontal direction. In order to investigate the device performance, numerical simulations are conducted in this study. In the experiments, the confocal microscopy is utilized to characterize the 3D hydrodynamic focusing flow fields within the device. Furthermore, flow cytometric measurement of standard fluorescence beads are also performed using the developed device to demonstrate its practicality for biological applications.

KEYWORDS

Microfluidics, Three-Dimensional Hydrodynamic Focusing, Polydimethylsiloxane (PDMS), Flow Cytometry

INTRODUCTION

Three dimensional (3D) hydrodynamic focusing is one of broadly utilized techniques for various microfluidic applications, including: micro flow cytometers and optofluidic waveguides [1,2]. As a result, many microfluidic devices capable of generating 3D hydrodynamic focusing have been developed in recent decades. However, the existing devices consist of multiple layers of microfluidic channels and multiple fluidic inlets [2,3]. Consequently, these devices often require complicated fabrication, tedious fluidic interconnections and professional operation. In this paper, we developed a single channel layer and a single sheath flow inlet microfluidic device capable of generating 3D hydrodynamic focusing for practical applications.

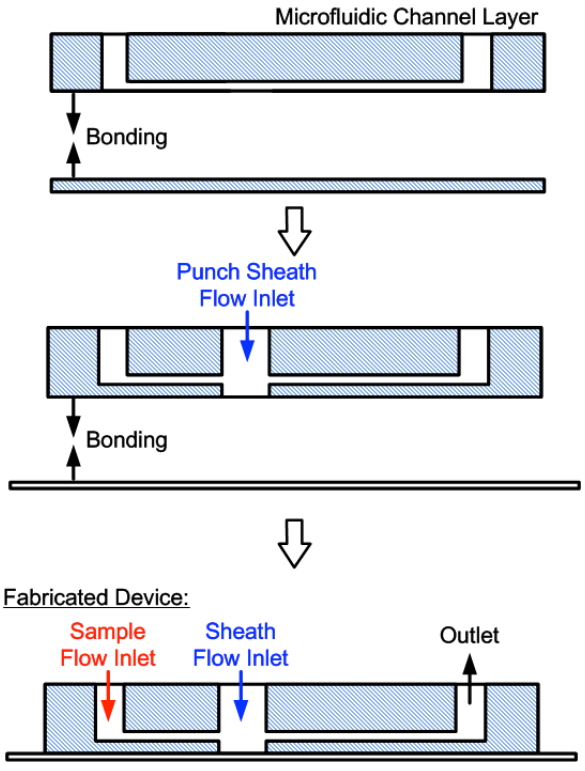

Figure 1. Fabrication process and schematic of the microfluidic device for 3D hydrodynamic focusing.

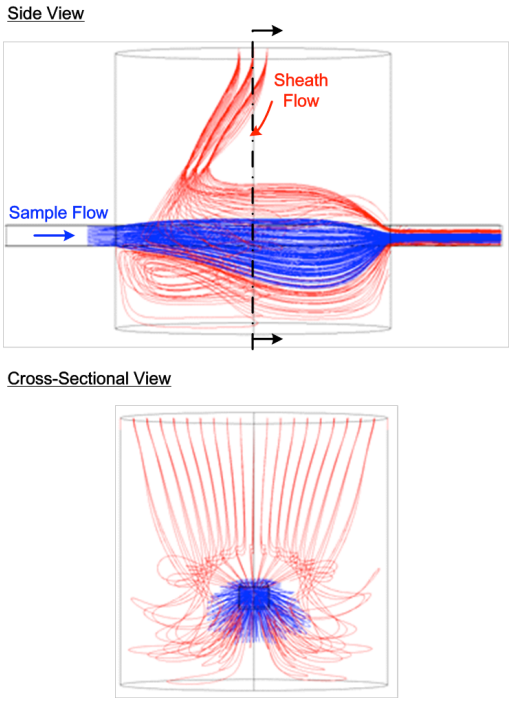

Figure 2. The simulation results when the total flow rate is 500 µl/min with the core/sheath flow rate ratio of 1:1. The simulation results show that the core flow is encircled by sheath flow introduced in the vertical direction and 3D hydrodynamically focused.

EXPERIMENT

The microfluidic device for 3D hydrodynamic focusing is composed of two PDMS layers: top and bottom layers, and a glass substrate as shown in Fig. 1. A straight microfluidic channel (dimensions: 150 μm by 200 μm) is patterned on the top layer using the well-developed soft lithography replica molding technique. A core flow inlet and an outlet are punched on the top layer. The bottom layer is a thin blank PDMS layer with thickness of 600 μm. The two layers are then irreversibly bonded using oxygen plasma surface treatment. A sheath flow inlet with a diameter larger than the channel width (2 mm) is punched in the middle of the channel. The sheath flow inlet also serves as an expansion chamber in the device. The bonded PDMS layer is then irreversibly bonded on to a glass substrate with thickness of 400 μm. Under specific flow conditions, the core flow possesses enough forward momentum, which prevents the stream contacting the sidewalls of the expansion chamber. Moreover, with the cavity fabricated in the bottom PDMS layer, the sheath flow has sufficient space to flow underneath the core flow.

Therefore, the sheath flow introduced in the vertical direction flows around the core stream in the horizontal direction. As a result, the 3D hydrodynamic focusing can be achieved by the simple device design with minimal interconnections. A three-dimensional computational fluidic dynamics model is constructed using a simulation software, COMSOL, to evaluate the device performance. Figure 2 shows the simulated flow field using the particle tracing functions, and the result shows the successful 3D hydrodynamic focusing. In the experiments, confocal microscopy is exploited to observe the flow while using water and fluorescein solution as the core and sheath flows, respectively.

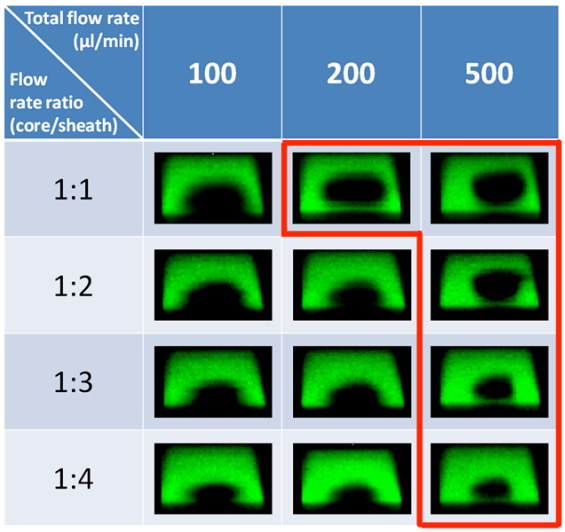

Figure 3. Table of Z-stack confocol images corresponding to various combinations of total flow rates and flow rate ratios (core to sheath) with 2 mm-diameter flow inlet using water and fluorescein solution as core and sheath flows, respectively.

RESULTS AND DISCUSSION

Figure 3 demonstrates the confocal images corresponding various combinations of flow conditions. The experiment results agree well with the simulated ones. Furthermore, the flow cytometric detection of fluorescence beads is performed using an inverted fluorescence microscope-based optical detection setup for demonstration. Figure 4 shows the time-domain detection signals, and an intensity histogram of 10 μm-diameter fluorescence beads. The coefficient of variation (CV) of the detected signals is 26.56%, which is similar to that obtained using the commercial flow cytometer (23.37%). The small CV suggests great 3D hydrodynamic focusing performance of the designed device.

CONCLUSION

In conclusion, the developed microfluidic device, requiring simple fabrication and minimal fluidic interconnections, provides a great solution to achieve 3D hydrodynamic focusing for various μTAS applications.

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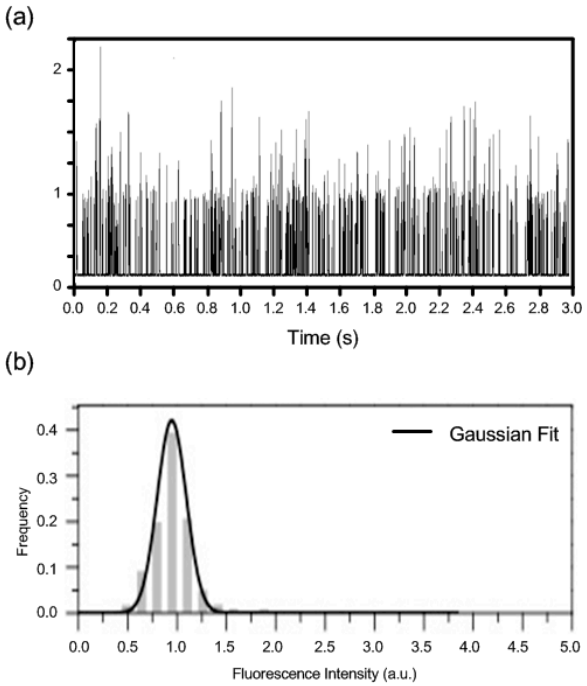

Figure 4. Flow cytometric measurement results of standard fluorescence beads using a device with a 2 mm-diameter sheath flow inlet. (a) Typical time-domain measurement results of 10 μm-diameter beads within a 3 sec-period with core and sheath flow rates of 100 and 400 μl/min, respectively. (b) Histograms of the measured peak fluorescence intensities and the Gaussian fit (black line) under the same flow conditions.

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