Novel Flow-Cell to Create a Sheath Flow with Adaptable Sample Flow Dimensions

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In this paper, a novel flow-cell is presented with a non-coaxial adaptable sheath flow for application in micro-fluidics systems. By two orthogonal control mechanisms, the vertical and horizontal dimensions of the sample flow can dynamically be adapted over a wide range. Experimental results are compared with the results from finite element simulations and show a good match.

Introduction

In this paper a novel flow-cell is presented in which the horizontal and vertical dimensions of the sample flow can be controlled dynamically, which allows application of many different sensing systems. The system has a non-coaxial sheath flow in which the sample flow touches one side of the channel (see Fig. 1); this assures a good contact with any sensor interface located on the channel bottom. Due to the limited interaction between sample flow and sheath flow, the sample flow can be considered as a virtual flow channel with adaptable dimensions (e.g. diameter 5% of physical flow-channel). As a result the presented system combines the advantages of a large diameter channel with those of a small diameter channel. Due to the small dimensions of the sample flow, the low detection limits of a small channel device can be achieved; at the same time, the large physical dimensions of the channel alleviate many problems such as clogging, air bubbles and fabrication tolerances.

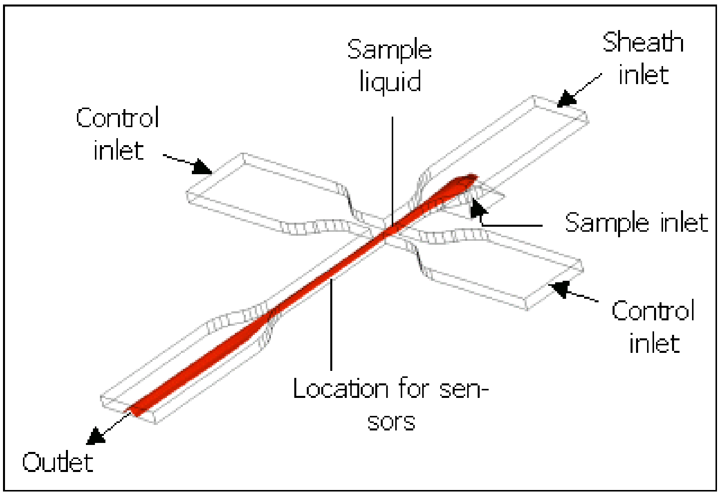

Fig. 1: Flow-cell to create the non-coaxial sheath flow; the relative flow-rate of the sample liquid (red) determines the height of the sample flow, adding or removing liquid through the control inlets controls the width.

One of the first realizations of sheath flow on a chip was achieved using with a 5-layer device [1]; recently less complicated devices were demonstrated [2], [3]. These devices do not offer dynamic, orthogonal control of the sample flow dimensions as presented in this paper. What is even more important: those devices were aimed at a traditional co-axial sheath-flow, which limits the possible sensors mainly to optical detectors, whereas the presented device is much more flexible.

Vertical Control of Sample Flow Dimensions

The sheath flow is formed by injecting the sample liquid vertically into the channel through which the sheath liquid is flowing; this forms a hydro-dynamically focused sample flow that still contacts the bottom of the flow channel (see Fig. 1). The vertical sample flow dimensions are controlled by the relative flow-rate of the sample liquid in relation to the flow-rate of the sheath flow in which it is injected. At higher relative flow-rates, the sample liquid penetrates further into the sheath liquid thereby increasing the sample flow height.

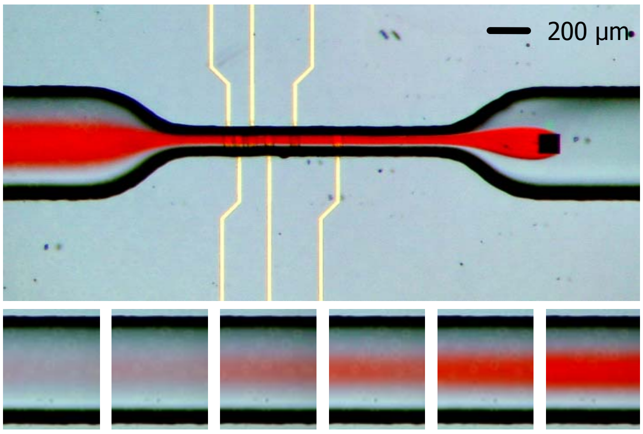

Fig. 2: Photographs illustrating vertical sample control; for increased sample flow-rates, the sample flow gets higher and the dye becomes more visible.

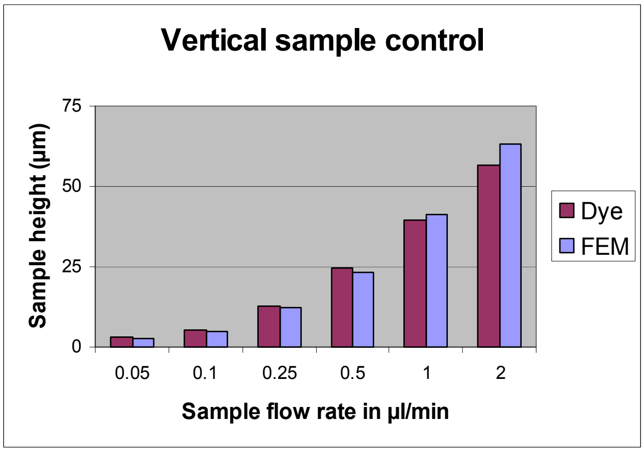

Fig. 3: Numerical data from measurements (dye) and simulation (FEM) for vertical sample flow control (sheath flow-rate constant at 10 μl/min).

The system was designed with help of simulations using the FEM-software package Coventorware. A series of measurements with a red dye was carried out to verify the simulation results. In the physical experiments, numerical data was obtained from the color information of photographs that were taken with a digital camera.

Some illustrative results are depicted in Fig. 2, and an overview of simulation and experimental results is depicted in Fig. 3. There is a very good match between both results. Fig. 4 demonstrates that not only the height, but also the complete distribution of sample matches very well.

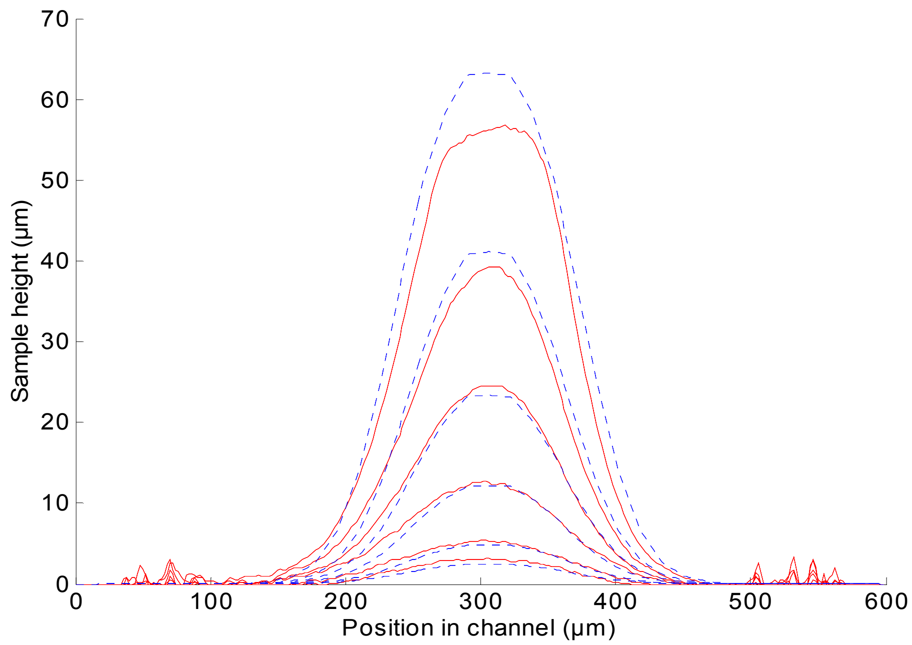

Fig. 4: Complete sample profiles for the same vertical sample flow control experiments as in Fig. 3 (dye: solid lines, FEM: dotted lines) demonstrating the good correspondence.

Horizontal Control of the Sample Flow Dimensions

The horizontal sample control is achieved by adding or removing liquid through two control inlets (see Fig. 1), located just down-stream of the sample inlet. Again, experimental results are compared with FEM-simulations. Some photographical results are depicted in Fig. 5. In Fig. 6, an overview of FEM and experimental results is depicted. The experimental and simulation results for the control of the horizontal dimensions show good correspondence.

Conclusions

A novel flow-cell with dynamic, orthogonal control of the sample flow dimensions has been presented that combines the advantages of large diameter and small diameter micro-channels. Experimental results on both vertical and horizontal control match very well with FEM-simulations. This allows predicting and controlling sample flow dimensions over a broad range of sizes and height-width ratios.

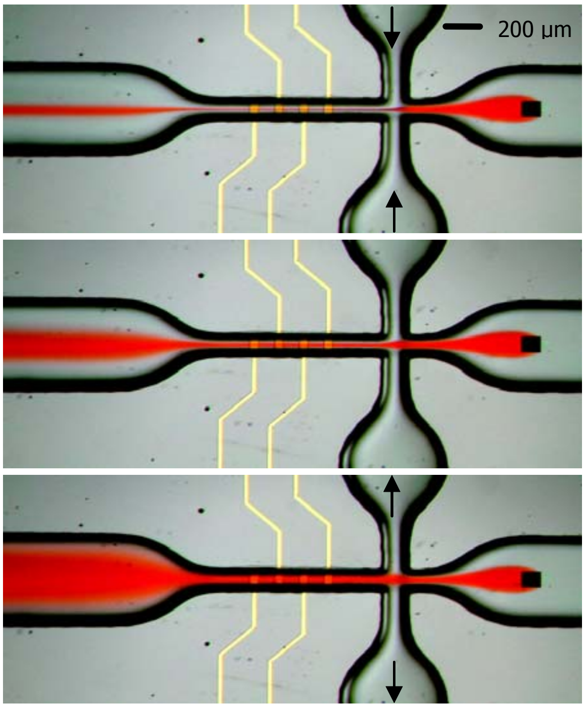

Fig. 5: Photographs illustrating horizontal control; adding liquid through the control inlets makes the sample flow less wide (top); removing liquid through the control inlets makes the sample flow wider (bottom).

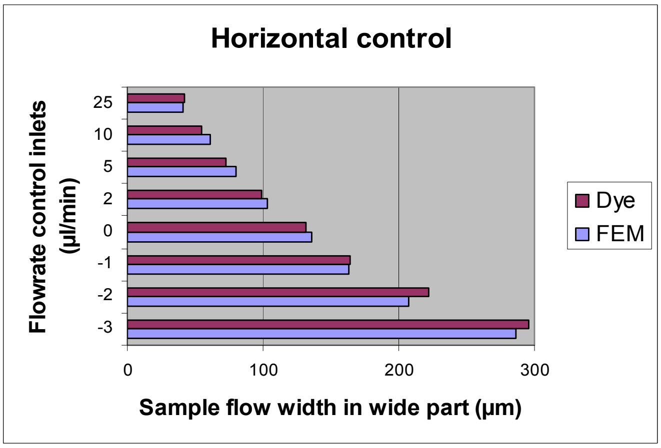

Fig. 6: Numerical data from measurements (dye) and simulation (FEM) for horizontal sample flow control (sheath and sample flow-rates constant at 1 and 10 µl/min, respectively).

Acknowledgements

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References

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