Hydrodynamic Flow Focusing for Microfluidic Cell Sorting Chip

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Abstract

Hydrodynamic flow focusing is an important requirement of microfluidic cell sorting devices. It allows the cells to arrive sequentially at the sorting location making detection easier. The simplest flow focusing configuration uses a three input Y-shaped microchannel. The sample enters the device from the central inlet and is squeezed by two side streams containing buffer (called "sheath" flows). The final focused width of the sample stream is purely a function of the flow-rates of central and sheath flows.

Based on literature survey [1-3] and our microfabrication capabilities, the channel width was chosen to be 200µm in our device (Fig. 1). The side (sheath) channels meet the central channel at 60 degrees [4]. This is because an angle of 30 degrees leads to very low pinching. On the other hand, an angle of 90 degrees builds up extreme pressures, which may be detrimental for the cells. The channel height was chosen to be 30 µm.

The device geometry is simulated using the Microfluidics Module of COMSOL Multiphysics® software with 3D simulation. In the current work, we have reported both steady state and time dependent simulations. The next step is to specify inlet and outlet velocities. We do so in terms of the flow rates. All three inlet flow rates were set as 10µl/min. We chose the "no-slip" boundary condition. This boundary condition ensures that the fluid comes to rest at the channel walls. The next step is to create a mesh. We chose the "extremely fine" mesh option for better results. However, this kind of a mesh slows down the simulation.

A C-shaped pressure profile is observed at the junction of three channels (Fig. 2b). The pressure is at maximum at the inlets and then gradually decreases as we travel along the channel. It appears that the velocity is maximum at the center of the channel. By varying the flow-rates different pinching widths were achieved. There is no theoretical limit to the pinching width; we found a practical lower limit to the pinched flow in simulations. This is because back flow happens from the side channels into main channel. In our simulations, the minimum width of 8µm was observed when the ratio of the sheath flow to the sample flow was 5.5.

The nature of the output barely changes even when the flow rates are increased or decreased, as long as all three flow rates are the same. When the sample flow rate is increased compared to the sheath flow, a bulge is produced at the junction. It keeps on increasing till the bulge starts touching the walls. As soon as it touches the walls in the flow-focusing zone, back-flow starts.

COMSOL Multiphysics® simulations were experimentally verified over the flow range 1-1000µl/min. The simulation output is cropped, rotated and its edges are matched with the experimental output figure. The simulation results match very well with what we get experimentally (Fig. 4).

Reference

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2. M. Rhee, et al. "Synthesis of Size-Tunable Polymeric Nanoparticles Enabled by 3D Hydrodynamic Flow Focusing in Single-Layer Microchannels."Advanced Materials 23.12 (2011): H79-H83.
3. H. A. Stone, A. D. Stroock, and A. Ajdari. "Engineering flows in small devices." Annu. Rev. Fluid Mech 36 (2004): 381-411.
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Figures used in the abstract

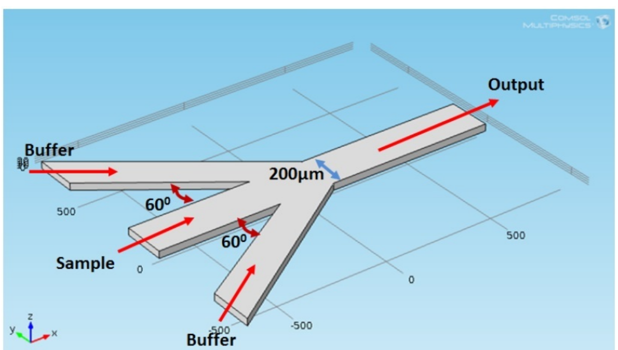

Figure 1: Flow focusing geometry.The figure shows the COMSOL model of the flow-focusing device. It has 200 µm wide channels and buffer inlets angled at 60 degrees with respect to the central sample input.

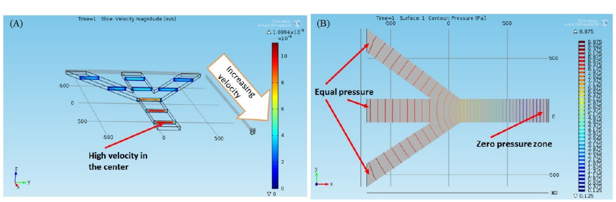

Figure 2: Velocity and pressure profile for flow-focusing device. (A)The flow velocity increases from zero value at the inlet to 1 mm/sec at the outlet. These simulation results show that once the cells enter the focused flow region, their velocity increases. (B) It can be seen that pressure decreases from inlet (10 Pa) to outlet (0.1 Pa). A C-shaped pressure profile is seen to be created at the intersection of the channels.

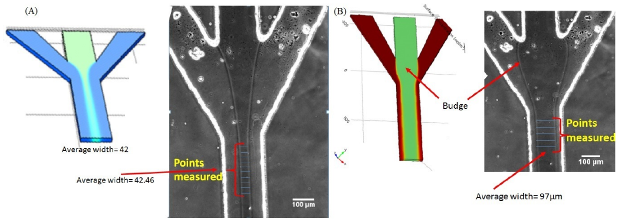

Figure 3: Comparison of COMSOL result with experiments under the same flow rates. (A)The figure on the left is the COMSOL simulation output. The dark blue colour indicates the buffer and the light blue colour at the center is the squeezed sample. The figure on the right shows the actual image taken during experiments performed with the same flow rates. (B) The figure on the left shows the COMSOL simulation output. The red fluid is the buffer and the light green fluid at the center is the squeezed sample. The figure on the right shows the actual image taken during experiments. At the junction, a bulge is seen as a result of the higher sample rate compared to the side channel buffers.

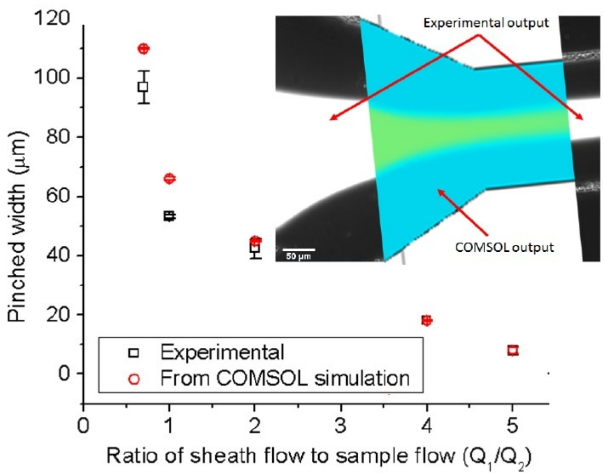

Figure 4: Overlapping of experimental and simulation results. Figure shows focus width as a function of flow-rate ratio Here y-axis depicts the focus-width in µm and x-axis depicts the ratio of sheath flow-rate to sample flow-rate Q1/Q2. The graph shows that the COMSOL simulation results are very close to the experimental data.