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High Throughput Acoustophoresis in Parallel Plastic Microchannels

Ryan Dubay[1], Ryan Silva[1], and Jason Fiering[1]

[1]Draper, Cambridge, MA, USA
E-mail: jfiering@draper.com

Introduction

Numerous studies have shown that ultrasonic stimulation in microchannels is effective for manipulating and separating particles within a fluid. [1] However, a drawback to the these microfluidic devices is limited throughput, typically on the order of 0.1 ml/min. Such rates preclude the expansion of acoustofluidics into applications such as bioprocessing, where throughput requirements may exceed 10ml/min. In principle, the performance of microfluidic acoustic devices can be preserved if channels are configured in parallel, but two hindrances to implementation are the cost of large micromachined chips in silicon or glass and the establishment of uniform excitation of each resonating microchannel in accordance with its wall thickness.[2]

Here we present an approach to fabricating parallel acoustofluidic devices and address both of these hindrances. The devices are constructed from a thermoplastic, enabling a large footprint while keeping the production cost low. Additionally, we take advantage of the ease of plastic fabrication and isolate each microchannel from its neighbor by an air gap. Thus, its mechanical behavior is close to that of a single independent microchannel, while multiple inlets and outlets converge in a bifurcated network. Using a parallel 4-channel test device, we show improved performance with the air gaps (slots) as the channels are used to focus red blood cells (RBCs) across a range of frequencies spanning both odd and even modes.

Methods

Two devices were fabricated from polystyrene sheets using a desktop micromill, and the layers were thermocompression bonded. Each contained a parallelized array of 4 channels with bifurcations connecting a single inlet and outlet. Bifurcations and overall path lengths were designed to maintain similar mean wall shear stress as well as equal flow distribution through each channel. One device had continuous walls (no slots) between the neighboring channels (Figure 1A), whereas the second included slots between them (Figure 1B). All other dimensions were constant, and channel and wall width were based on a previous polystyrene single-channel design demonstrated to focus RBCs.[2] Chips were mounted to identical piezoelectric transducers. Diluted whole blood (7.5% hematocrit) flowed through each chip at a total rate of 100 µL/min.

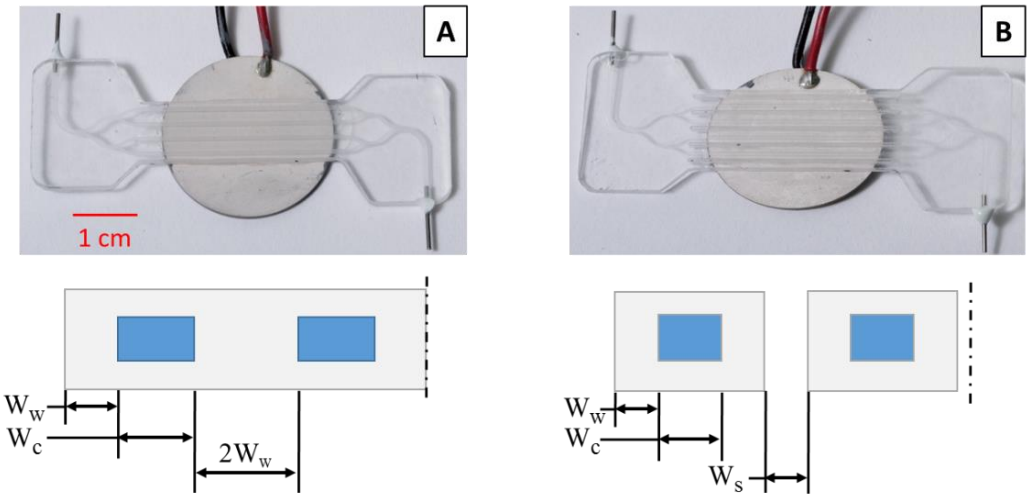

Figure 1. Photographs of parallel channel device mounted to transducer and cross section diagrams below to show relative dimensions (not to scale). A) No slot design with W_w width of the wall, W_c width of the fluid cavity, and dashed line indicating symmetry plane. B) Slotted design where dimensions are the same as (A), and W_s is the width of the slot.

Results

A microscope image was taken at the downstream end of each channel as it was driven at frequencies from 0.300—1.75 MHz in 10 kHz intervals, while holding temperature and average dissipated power constant (26ºC, 2.0 W). The images were used to quantify the degree and position of RBC focusing at each frequency. Raw image files were inverted such that pixel intensity correlates to RBC concentration and pixel intensity was measured across the width of the channel as plotted in Figure 2. A peak in pixel intensity corresponds to a stream of focused RBCs. To further compare uniformity of blood cell focusing among channels, the prominence of the peaks in pixel intensity were calculated at each frequency. Prominence is defined as the difference between the highest peak and the max of the flanking minor peaks.[3] The optimum frequency, i.e., that with the highest prominence overall, was tabulated for the odd and even modes (Table 1).

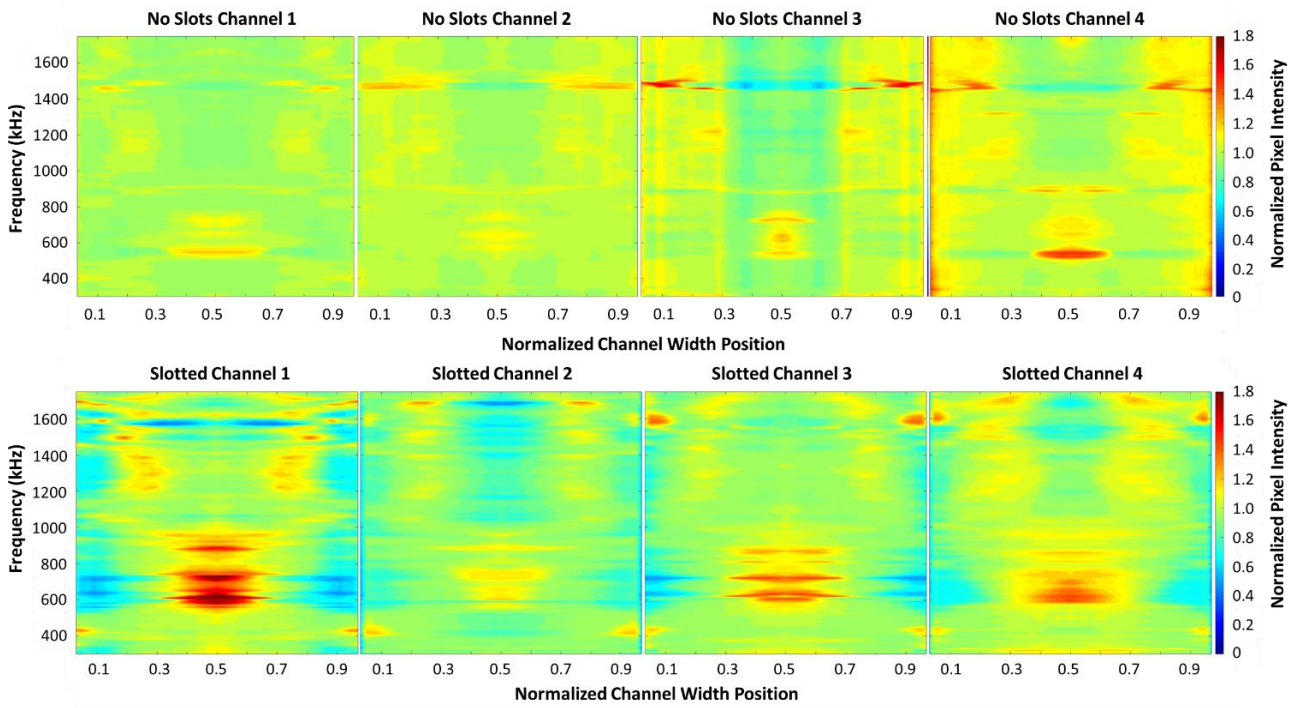

Figure 2. Pixel intensity (showing maximum focusing of RBCs as red) at each frequency and across width of channel. No-slot device (top), and slotted device (bottom). To eliminate illumination artifacts, pixel intensity was normalized to mean for each image, and the right half of the channel is a mirrored image of the left to enforce symmetry.

Table 1. Analysis of optimum frequency for each channel for no-slot and slotted device, showing mean and standard deviation among the four channels. Optimum frequency is that which produced highest peak prominence in pixel intensity. In odd mode RBCs focus to the center axis of channel; in even mode bilateral focusing streams were observed.

Device Design	Odd Mode Mean Frequency (kHz)	Odd Mode Std. Dev. Frequency (kHz)	Even Mode Mean Frequency (kHz)	Even Mode Std. Dev. Frequency (kHz)
No Slots	577.5	45.00	1475.0	23.80
Slotted	615.0	17.32	1555.0	10.00

Conclusion

The results suggest that the slotted device has improved performance over the no-slot device. Figure 2 shows that the slotted device has higher dynamic range in pixel intensity, which corresponds to stronger acoustic focusing of RBCs. Table 1 shows that in the slotted device, the optimum excitation frequency for both odd and even modes is more repeatable from channel to channel than in the no-slot device. This study indicates that a large scale array of microchannels could be fabricated from plastic for high throughput applications.

References

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