Size-independent separation of vertically focused particles using the principal component of acoustic radiation force in a continuous flow

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Introduction
We demonstrate a microfluidic method for the continuous separation of similar sized polystyrene (PS 5 µm) and polymethylmethacrylate (PMMA 5 µm) particles using the vertical component of acoustic radiation force. Previously our study group[1] and Ma et. al[2] utilized the forces in the horizontal plane for the manipulation of particles based on its mechanical properties. A particle suspended in fluid experiences a direct acoustic radiation force (ARF) when a traveling SAW originating from interdigitated transducer (IDT) patterned on piezoelectric substrate coupled with the fluid inside a microfluidic channel at Rayleigh angle (~22°). The ARF can be resolved into vertical $F_v$ and horizontal $F_h$ components where the former being 2.5 times greater than the latter. To date, majority of the SAW-based microfluidic devices rely on horizontal component of the ARF that migrates the pre-aligned particles laterally across the microchannel width.[1]–[3] Although vertical component of the ARF is more than twice the horizontal component, it has being ignored in the past. In the present work, we utilized the vertical component of acoustic radiation force for the continuous separation of similar sized particles (different materials) by steeply focusing them in the vertical plane. This method enables high-throughput and efficient separation of particles over a wide range of flow rates.

Working Mechanism
The acoustofluidic particle separation device is composed of a piezoelectric substrate (LN) with interdigitated transducer (IDT) deposited on top of it. A straight PDMS microchannel having two inlets and two outlets port is mounted above the IDT in such a way that the IDT is placed between the second inlet and first outlet. A mixture of PS and PMMA particles solution is injected through the first of the two outlets with the flow rate of $Q_1$ (500µL/hr) and a sheath flow in the form of deionized water is introduced through the second outlet with the flow rate of $Q_2$ (4500 µL/hr) to focus the particles mixture in the downward streamlines before the separation zone. Similarly, one of the two outlets was used to suck the fluid at a flow rate of $Q_3$ (500µL/hr) or $Q_4$ (4500 µL/hr) while the remaining fluid was collected at the other outlet ($Q_1$ or $Q_2$).

Results
During power off, all the particles were keep on flowing through the lower streamlines and collected through the second outlet, results in no separation (see Figure 1(A)). Previous studies have shown that the deflection of PS particles is greater than that of the PMMA particles for a particular frequency range (125-140MHz).[1] So, once the AC signal of 140MHz was given to the device, the horizontal component $F_h$ of ARF slowed down the motion of the particles against the direction of flow due to resultant drag force $F_d$ on the particles and the major component $F_v$ of ARF pushed both PS and PMMA particles in the upper streamlines based on their acoustic impedance. By manipulating the flow rate at both the outlets PS particles were collected through the first outlet and PMMA particles were collected through the second outlet as shown in Figure 1(B).

Sample analysis
The collected sample at each outlet was analyzed by using hemocytometer chip (see Figure 2(A)). Five samples (10 µL each) from each outlet were examined for particles counting. PS and PMMA (5 µm) particles were collected through 1st and 2nd outlet with 86.70% and 98.1% efficiency respectively (see Figure 2(B)). The comparatively low efficiency at the 1st outlet was attributed to the large size distribution of manufactured PMMA particles. In future, we are keen to use NIST stand particles to minimize the problem of the large size distribution of particles. In addition to the separation of PS and PMMA particles, we are looking to further explore the properties of different material particles like fused silica, melamine, glass and silicon dioxide microspheres etc.
Figure 1: A schematic diagram showing the vertical component of acoustic radiation force-based particle size independent separation device composed of a straight interdigitated transducer patterned on the lithium niobate substrate and PDMS microchannel positioned on top of it. (A), (B) Showing the top side views and particles separation zone when the SAW was turned off and on respectively. Particles are slowed down by the horizontal component of ARF $F_h$ and pushed in the upward direction depending on acoustic impedance of particles due to the vertical component of ARF $F_v$.

Figure 2: Experimental images (A) and sample analysis (B) of particles collected from 1st and 2nd outlet.

Conclusion
We currently separated two different material PS and PMMA particles having a similar diameter (5 $\mu$m) but different acoustic impedance in a continuous flow by utilizing the larger component of ARF. Our future target is to manipulate fused silica, melamine, glass and silicon dioxide microspheres using a similar technique.

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