Inertial microfluidics-based submicron-particle concentration device

[1]Se-Ung Lee, [1,2]Sung Yang*
[1]School of Mechanical and Robotics Engineering, [2]Department of Biomedical Science & Engineering,
Gwangju Institute of Science and Technology (GIST), Gwangju, 61005, Republic of Korea

Abstract

Inertial microfluidics is a technology that can concentrate or separate particles in microfluidic channels and can be utilized in the preprocessing process of clinical samples. However, as the size of particles decreases, the effect of inertial force decreases, and the size of the device must also decrease in order to manipulate sub-micron particles, which increases the channel resistance. In this study, we propose a device that manipulates sub-micron particles while maintaining high throughput by altering the channel cross-section with a modified herringbone pattern and contraction-expansion array(CEA) channel combination. Generally, inertial lift forces from Poiseuille flow form two or more particle equilibrium positions inside the channel. The repeated height and width changes can induce a secondary flow and additional force perpendicular to the main flow direction, which can shift the particle equilibrium positions. A numerical simulation confirmed that the proposed structure moves small particles closer to the wall. It is expected that particles, accelerated toward the wall by the spiral flow from the herringbone pattern, will be further shifted by the CEA shape. Experiments were performed using 1um polystyrene fluorescent beads. 1um particle reached distance ratio between wall to concentrated stream as 0.06 , for FWHM proposed design reached 0.167, and the concentration rate of 1.5 times at 5mL/h flow rate.

Introduction

- **Concentration and separation of sub-micron bio particles**
  - Biosensors have a problem of sensitivity in low concentration.[1]
  - Conventional methods such as centrifugation are not suitable for concentrating small concentrations of submicron-sized bacteria.
  - Reducing the channel size for smaller particles increases inertial force on them, thereby raising channel resistance. [2]

- **In this work**
  - Development of a device that separates and concentrates particles($D_p \leq 1\mu m$) in a fluid using inertial microfluidics without sheath fluid.
  - We integrated contraction expansion array with herringbone to narrow the concentrated flow width and shift the separated flow toward the channel walls.

Device schematic

- **Device design**
  - Channel : 50 μm × 25 mm × 20 μm (W × L × H)
  - Herringbone structure height: 30 μm (total height: 50 μm)

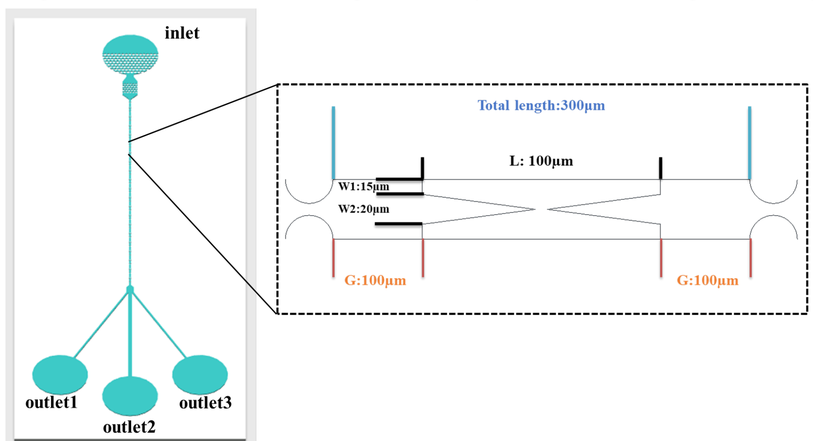

Fig. 1. Schematic of sub-micron concentration device.

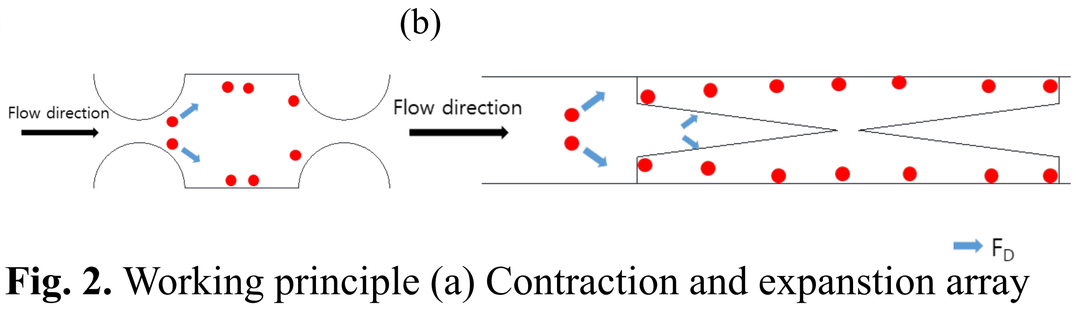

Fig. 2. Working principle (a) Contraction and expanstion array channel(CEA) (b) Herringbone sturcture

- **Working principle**
  - As the channel width narrows and then expands, the particles experience a secondary drag force toward the channel walls.
  - The height difference creates resistance, moving fluid from lower to higher regions, with a secondary drag force pushing from the channel center toward the wall.
  - The resistance design directs fluid and particles to specific positions upon entering the herringbone structure.

Experimental Result

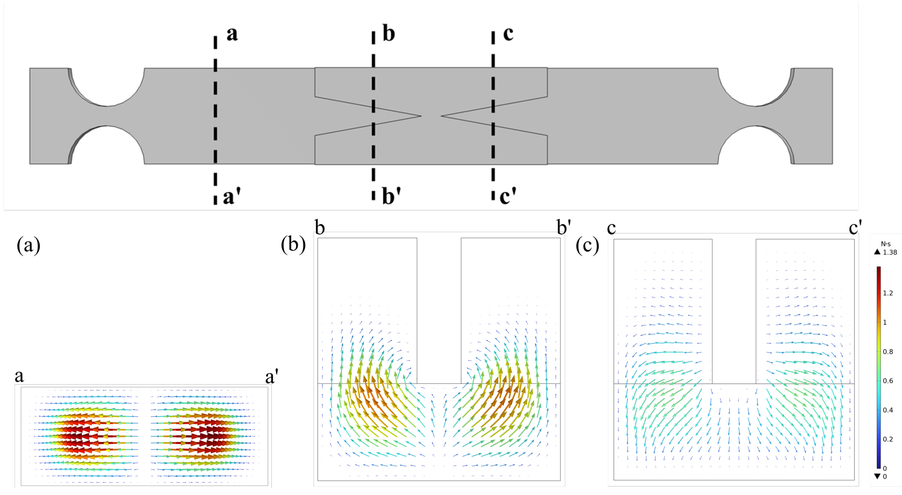

Fig. 3. Momentum direction acting on a particle (a) aa' cross section (b) bb' cross section (c) cc' cross section

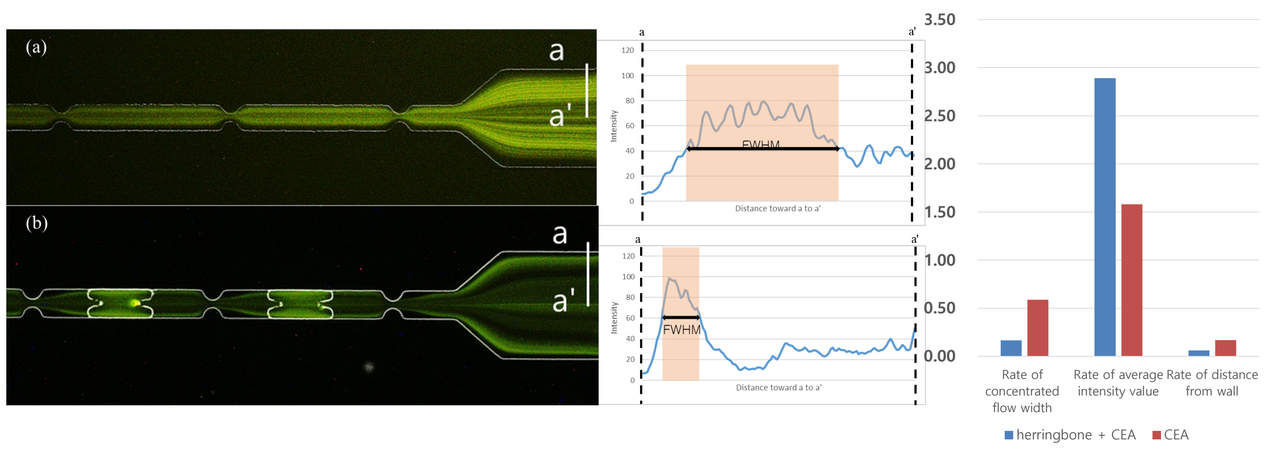

Fig. 4. At 5mL/h injection flow rate, distribution of 1μm fluorescent particles across the microchannel (a) A Conventional CEA channel (b) A Herringbone integrated CEA channel with a lower channel height of 20μm and an upper channel height of 50μm (c) calculated results

- **Results**
  - Rate of concentrated flow width: **0.17**

$$Rate\ of\ concentrated\ flow\ width = \frac{FWHM}{total\ Width/2}$$

  - Rate of average intensity value: **2.89**

$$Rate\ of\ average\ intensity\ value = \frac{average\ intensity_{FWHM}}{average\ intensity_{non-concentrated\ stream}}$$

  - Rate of distance from wall: **0.06**

$$Rate\ of\ distance\ from\ wall = \frac{starting\ point\ of\ FWHM}{total\ Width/2}$$

Conclusion

- **Ability of the proposed device**
  - Confirmation of the possibility of manipulating sub-micron-sized particles without external force
  - Manipulating micro-particle focusing in the direction of each side wall to achieve higher separation and concentration efficiency
- **As future work**
  - Integration with a device for measuring bacterial concentration via DEP

Reference

1. A. Abbaspour *et al.*, *Biosens. Electron.*, (68) 149-155, 2020.
2. Xiang, Nan, and Zhonghua Ni, Lab on a Chip, 22.24, 4792-4804, 2022.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT). (No. NRF-2021R1A2C3008169) .