CONTINUOUS PARTICLE SEPARATION USING REPULSIVE FORCE OF ION CONCENTRATION POLARIZATION

Hyungkook Jeon, Sung Hee Ko, Kwan Hyoung Kang

Department of Mechanical Engineering, Pohang University of Science and Technology, Korea

ABSTRACT

In many research groups, ion concentration polarization (ICP) phenomenon has been used in many application fields, such as sample preconcentration, micro mixer and desalination. Here, we present a new continuous-flow separation method based on the ICP. The configuration of this system is similar to that of conventional nanofluidic concentration device, so that electrical force takes place near the nanojunction when applying external voltage. Using the force, we performed separation of particles depending on their sizes. This research might be very meaningful in developing an integrated separation device which can separate various kinds of samples in one chip.

KEYWORDS

Ion concentration polarization, particle separation

INTRODUCTION

Under applying voltage across a nano-junction or an ion perm-selective membrane, ion concentration polarization (ICP) phenomenon occurs around the membrane. ICP literally means an electrochemical transport phenomenon that ion concentration becomes polarized across the membrane. In the case of cation selective membrane, when voltage is applied, the ion concentration would decrease around the anodic side of the membrane and increase around the cathodic side of that. Those two regions are so called 'ion depletion region' and 'ion enrichment region', respectively. The ICP phenomena can be used to many engineering fields, but the main application of ICP is sample preconcentration.[1] When DC voltage is applied to the concentrator, repulsive force is applied at charged molecules in the anodic side of the nano-junction, such as electrophoresis and dielectrophoresis. In this case, molecules are accumulated at specific region due to force balance when additional flow (electroosmotic or pressure driven flow) is applied at the concentrator. This accumulation strategy has been used to many biological engineering such as immunoassay and enzyme assay.[1] For biochemical analysis, on-chip separation is an essential and important step.[2] Until now, various separation methods in microfluidic systems have been developed including separation based on microstructures,[3] laminar flow,[4] dielectrophoresis,[5] etc. In this work, we developed a new particle separation device based on ICP and demonstrated particle separation depending on the size. The mechanism of the separation device is related to repulsive force generated around depletion region, such as electrophoresis and dielectrophoresis.

EXPERIMENT

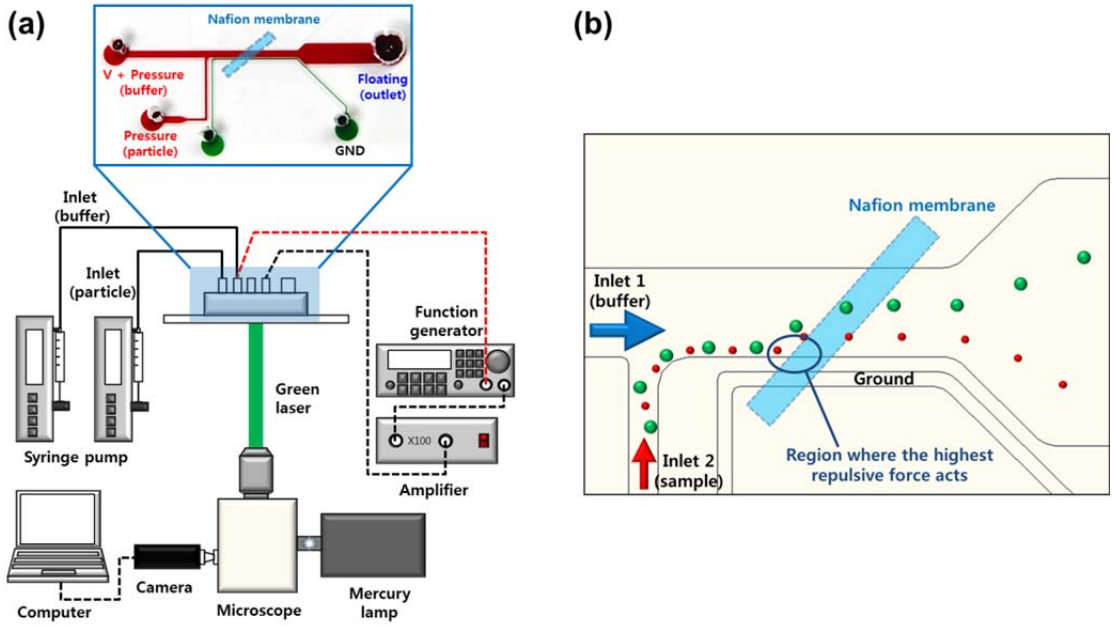

Figure 1. Schematic diagrams of (a) the experimental set-up and (b) particle separation.

Figure 1(a) shows a schematic diagram of the experimental set-up. The separation device was composed of a PDMS microchannel and Nafion membrane (ion-perm-selective membrane). The PDMS microchannel was fabricated using standard photolithography fabrication process (main channel width: 600 μm, height: 43 μm, channel length: 2.4 cm; from inlet 1 to outlet). Using microflow patterning method, we deposited a thin strip of Nafion membrane on the glass substrate,[6] and the fabricated PDMS microchannel was bonded with the membrane

978-0-9798064-5-2/μTAS 2012/$20©12CBMS-0001

patterned glass substrate via plasma bonding equipment. To enhance the efficiency of particle separation, the Nafion membrane was patterned with a slanted angle of 45°, as shown in Fig. 1(a). Figure 1(b) represents a schematic diagram of particle separation. Since the magnitude of the repulsive force is the highest near the membrane edge adjacent to the grounded channel, as shown in Fig. 1(b), particles were required to focus on the sidewall adjacent to the grounded channel for more accurate separation experiment. To do this, the particles from Inlet 2 were focused on the sidewall by using flow focusing method. In this experiment, we used fluorescent particles with diameters of 4.8 μm and 9.9 μm,. Applied flow rate and voltage were controlled by syringe pumps (Pump 11 Elite, Harvard Corp.) and a function generator (33220A, Agilent) connected to amplifier (A800, FLC electronics), respectively. To observe movement of fluorescent particles, we used a microscope (Axiovert 200, Carl zeiss) with a RGB filter and a CCD camera (Pco Sensicam, Pco. Imaging).

RESULTS AND DISCUSSION

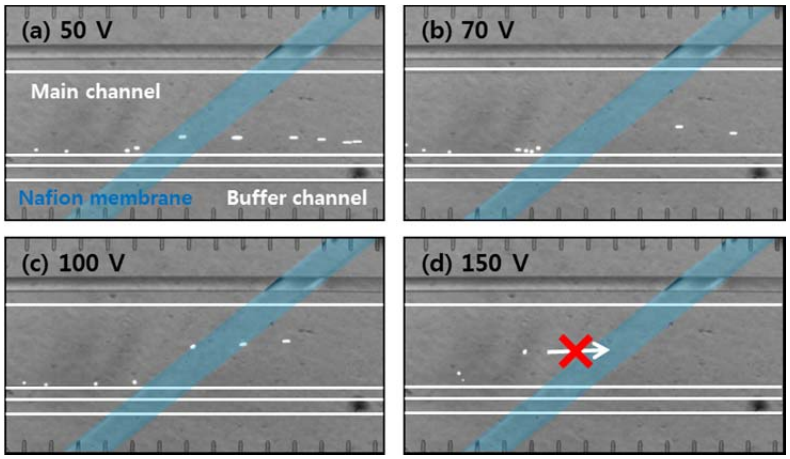

Figure 2. The movement of particles depending on voltage strength.

Prior to separation of particles, we observed movement of particles with applied voltage. The higher voltage we applied, the more particles were repelled from the side wall, as shown in Fig. 2. But, particles cannot pass the membrane when applied voltage is too high (over 150 V) as shown in Fig. 2(d). Electric field gradient takes place around the membrane due to concentration gradient in the depletion region with very low ion concentration. Due to existence of the electric field and electric field gradient, both electrophoretic (EP) and dielectrophoretic (DEP) force could be applied at particles. Since particles used in this experiment are negatively charged and have lower dielectric constant than buffer solution, EP and DEP are applied in the opposite direction of particle movement by the hydrodynamic flow. Thus, we conjecture that repulsive force might be EP and DEP, and particle could not pass the membrane due to the strong repulsive force compared to hydrodynamic force by pressure driven flow (Fig. 2(d)).

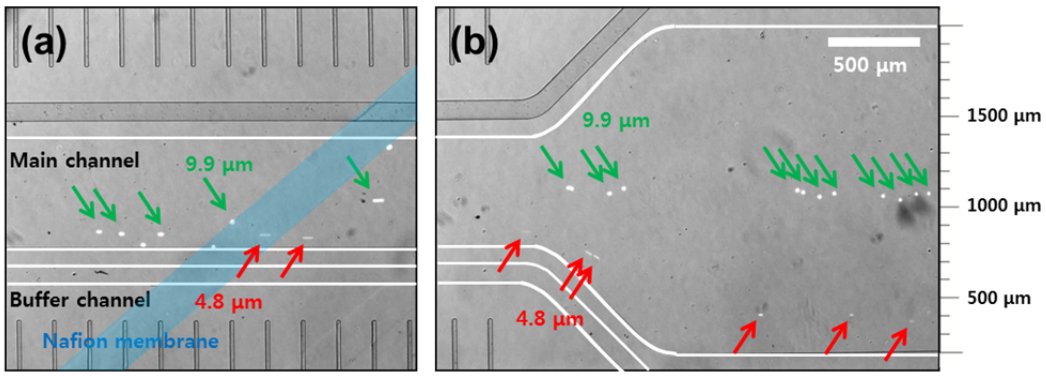

Figure 3. Separation of particles with diameters of 4.8 and 9.9 μm: the movement of particles in (a) the main channel and (b) the broadened outlet channel.

Figure 3 represents experimental results for particle separation (4.8 μm and 9.9 μm). We observed that 9.9 μm particles were repelled more than 4.8 μm particles, and the short separation distance between them was amplified by broadened outlet channel (width change: from 600 to 1800 μm). We also tried to separate nano-sized particles (particle size: 100 nm and 500 nm) as shown in Fig. 4. In the both cases, large particles were repelled more than small particles. The electrophoretic mobility of particles used in this experiment is as follows; 9.9 μm (-4.78×10^{-8} $m^2/V \cdot s$), 4.8 μm (-2.95×10^{-8} $m^2/V \cdot s$), 500 nm (-5.32×10^{-8} $m^2/V \cdot s$) and 100 nm (-3.07×10^{-8} $m^2/V \cdot s$). As mentioned before, EP and DEP are applied to particles as the repulsive force. In the case of Fig. 3, since both size and mobility of the 9.9 μm particle are larger than that of the 4.8 μm particle, 9.9 μm particles were repelled more

than 4.8 μm particles by stronger force strength of EP and DEP. In the case of Fig. 4, electrical force applied at 500 nm particle is also stronger than 100 nm particle. But the size of particle is very small compared to that of Fig. 3, so we guess that the force by DEP might be very weak because magnitude of the DEP is proportional to the volume of the particle. Thus, in the case of 100 nm and 500 nm particles, we conjecture that the repulsive force is only EP, not DEP.

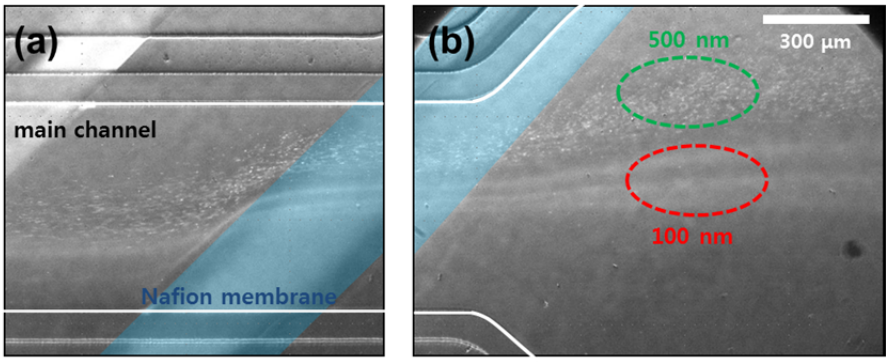

Figure 4. Separation of particles with diameters of 100 and 500 nm: particle movements in (a) the main channel and (b) the broadened outlet channel.

CONCLUSION

In this work, we have demonstrated a new continuous-flow separation device based on ICP. We observed larger particles were repelled more than smaller ones under same applied voltage. Using this, we performed continuous particles separation depending on size of particles. Especially, since our separation device makes possible to separate nano-sized particles continuously, we expect that this separation device can be used to biochemical analysis system. To examine the mechanism of separation more accurately, it is needed to analyze the characteristics of electrical forces induced around the Nafion membrane or depletion region, quantitatively. In the future work, we will perform analytical or numerical studies to examine the accurate mechanism of separation and separation experiments for various kinds of samples, such as cell, nano-sized particle, protein, DNA, etc.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) Grant No. R0A-2007-000-20098-0 funded by the Korea government (MEST).

REFERENCES

[1] S. J. Kim et al., *Nanofluidic concentration devices for biomolecules utilizing ion concentration polarization: theory, fabrication, and applications,* Chem. Soc. Rev., Vol. 39, pp. 912-922, (2010).
[2] D. R. Reyes et al., *Micro total analysis systems. 1. Introduction, Theory, and Technology,* Anal. Chem., Vol. 74, pp. 2623-2636, (2002).
[3] V. VanDelinder & A. Groisman, *Perfusion in microfluidic cross-flow: Separation of white blood cells from whole blood and exchange of medium in a continuous flow,* Anal. Chem., Vol. 79, pp. 2023-2030, (2007).
[4] J. Takagi et al., *Continuous particle separation in a microchannel having asymmetrically arranged multiple branches,* Lab Chip, Vol. 5, pp. 778-784, (2005).
[5] K. H. Kang et al., *Continuous separation of microparticles by size with Direct current-dielectrophoresis,* Electrophoresis, Vol. 27, pp. 694-702, (2006).
[6] J. H. Lee et al., *Multiplexed proteomic sample preconcentration device using surface-patterned ion-selective membrane,* Lab Chip, Vol. 8, pp. 596-601, (2008).

CONTACT

Kwan Hyoung Kang 82-54-279-2834 or khkang@postech.ac.kr