PDMS 마이크로 채널에서의 전기삼투 흐름

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Electroosmotic flow in the micro-channel made of PDMS

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I. Introduction

Since the initial description of the "lab-on-a-chip" concept, there has been an explosion of interest in the development of analytical systems utilizing the microchip format. So-called micro-total analysis systems(μ-TAS) offer ways to achieve fast, highly efficient separations in a miniaturized planar device that includes all of the components necessary to perform and monitor the separation. Micro-fabricated systems have numerous potential benefits, including automation, reduced solvent waste, increased precision and accuracy, and disposability. One can also envision these micro-analytical systems in portable analyzers for clinically or environmentally important analysis.

One of the earliest examples of μ-TAS systems is the introduction of capillary electrophoretic separation in electroosmotic flow in micro-fabricated channels. Numerous papers have been published since the first proof-of-concept papers demonstrated the enormous analytical potential for miniaturized separation devices. Controlling the electroosmotic flow is of primary importance for a reproducible and precise fluid control in micro-fabricated fluid networks. A possible way to achieve this is by applying an additional perpendicular external voltage across the wall of the micro-channel. Polson groups used micro-channel which can be altered with external voltages smaller than 120V[1]. Schasfoot, et al. had a similar approach, in which the micro-channels were surrounded by a thin, free-standing and fragile nitride wall(390㎚ thick)[2]. Ocvirk, and coworkers introduced electrokinetic control of fluid flow in the native PDMS(polydimethyl siloxane) capillary electrophoresis devices[3]. Electroosmotic flow was observed to approach to the cathode for the buffer systems(pH 3-10), in the presence or absence of hydrophobic ions derived from tetrabutylammonium or dodecyl surfate.

In this work, micro-channel was been made using PDMS(Polydimethyl siloxane) and the fluid passes through the micro-channel by the principle of electroosmosis. Electroosmosis is the bulk flow of liquid due to the effect of the electric field on counterions adjacent to the negatively charged capillary wall. Electroosmotic flow is generated when the surface of channel has negative charge. But in the micro-channel made by PDMS, the wall is not charged. To make the wall negative, PDMS is exposed to corona discharge. Consequently, silanol group is formed on the surface of PDMS and the wall of PDMS is changed to hydrophilic channel. But this negativity is vanished in approximately one hour. Therefore, polar solution is injected through the micro-channel to maintain the negative charge of the wall. The parameters which influence electroosmotic flow rate are electric field, zeta potential and physical properties of solvents. Therefore the effects of these parameters are also considered.

II. Theory

Electroosmosis and electrophoresis occur in the inner region of the capillary during capillary electrophoresis(CE) operation. The electroosmosis and electrophoresis occur due to the electric charge on the capillary surface and the particle, respectively[4]. The charge density of a surface is an innate electrostatic property, which is measyred by ζ-potential. ζ-potential is a more useful property in the study of the electroosmosis and electrophoresis, because it is the resulting electrokinetic property including the effect of the surroundings.

When an charged surface is in contact with the aqueous electrolyte solution, the ions of different sign, counterions, gather near the surface. And some of them are tightly attached and immobile, forming Stern layer. The rest are free enough to form the concentration distribution through the diffuse layer. These layers are called electric double layers. If there is no counterion around the charged surface, the magnitude of the electric potential is determined by the applied electric field. However, if there are counterions near the charged surface, some of those ions contribute to the formation of the Stern layer and the rest are distributed to the diffuse layer as a function of the distance from the surface due to the magnitude of the electric potential. The potential at the 'surface of shear' which is an imaginary surface from which the diffuse layer begins is known as ζ-potential. ζ-potential is related to the movement of the movable counterions near the surface. Thus electroosmosis and electrophoresis should be related to the ζ-potential which is the representative electrostatic property of the charged surface. Electroosmosis is the movement of the eluant phase or mobile phase, which is usually electrolyte solution. The electroosmotic velocity(U_{eo}) of the eluant is expressed as

$$U_{eo} = \frac{\varepsilon \zeta E}{4\pi \eta} \tag{1}$$

(E: electric field, ε: dielectric constant, ζ: zeta potential, η: viscosity)

below assuming that the double layer thickness is very small compared with the capillary radius. Since the capillary wall made of PDMS is exposured to corona discharge before operation, it charges negatively. And an electric double layer is formed on the capillary wall where the counterions have the positive charge. When an electric field is applied along the channel, those counterions react to the electric field and move toward the negative electrode.

The electroosmosis is the characteristic feature of CE which enhances the efficiency of CE as an analytical tool. The electroosmosis makes all solutes move to the one end of the capillary, that is, to the direction of the negative electrode in our case. The phenomenon of the electroosmosis plays an important role where the charged surface exist, as well as in CE. Sims et al.[5] studied the ionic partition coefficients in the cylindrical pores with charged surface by analyzing the electroosmosis to speed up liquid chromatography. The electroosmotic flow produced during CE operation satisfies creeping flow limit, i.e. low Reynolds number limit. Thus the velocity of a particle(U_p) in CE system can be written as

$$U_p = U_{eo} + U_{ep} \tag{2}$$

which is a superposition of the electrophoretic(U_{ep}) and the electroosmotic(U_{eo}) velocity.

III. Experiment and Result

The procedure to make micro-channel using PDMS is as follows. First, the pattern is transcribed to Si wafer using typical photolithographic method. The thickness of

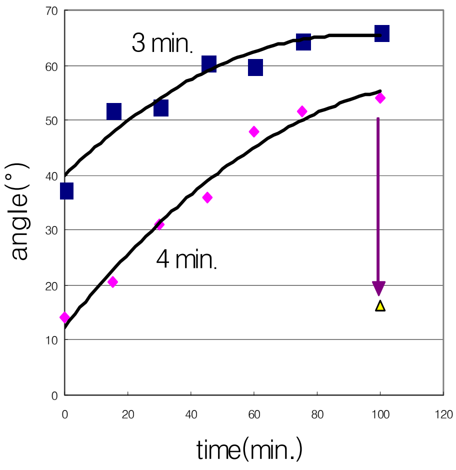

Fig.1 **Contact angle of water on the PDMS surface. As contact angle becomes smaller, the surface becomes more hydrophilic**

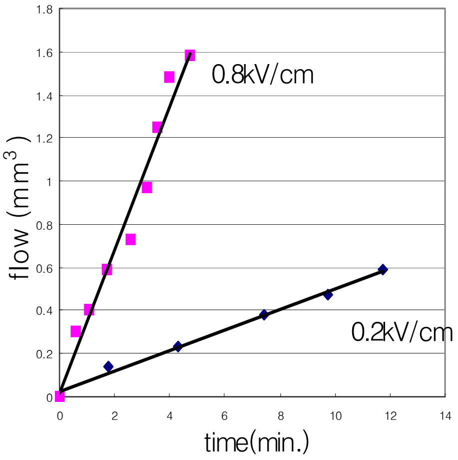

Fig.2 **Electroosmotic flow according to time. The slope of graph is electroosmotic flow rate and we can calculate ζ-potential from flow rate.**

photoresist(PR) determines the depth of micro-channel. After photolithography processing, wafer is coated by TMCS(trimethylchlorosilane) for easy separation of wafer and PDMS. Then, PDMS solution is poured onto wafer. Bubbles in PDMS are eliminated in the vacuum, and PDMS is cured at 70℃ for 2 hr. After pulling apart PDMS from wafer, holes for inlet and outlet of fluid is formed. Finally, PDMS which has a channel is pasted to the other PDMS plate. The role of corona discharge is to change the hydrophilicity of PDMS. When the surface is hydrophilic, the silinol group of surface can combine with the other silanol group to form bondings between them irreversibly. Corona discharge plays the other important roles. To generate electroosmotic flow, the necessary negative charge at the wall is obtained by corona discharge treatment. After exposured to corona discharge, PDMS surface is changed to hydrophilic surface. If the surface is hydrophilic, the contact angle of water on the surface about water is low as shown in Fig.1. And this means that PDMS surface has negative charge. But the hydrophilicity of the surface is maintained for 1-2 hr. in the air. Therefore, PDMS micro-channel is exposured to corona discharge twice. First is when PDMS plate is combined, and the second is before fluid is fed into the channel. After polar solution fills the channel, hydrophilicity of the surface lasts for several days.

Fig.2 shows flow rate by the electroosmotic flow. The size of channel is 200㎛×10㎛×49 ㎜. Deionized water solution which contains disodium phosphate was used. The concentration of disodium phosphate is 4 mM. When one mole of disodium phosphate is solved in deionized water, it forms 2 moles of Na^+ and 1 mole of HPO_4^-. Negative wall of PDMS attracts sodium ions, forming electric double layer. As electric field becomes stronger, flow rate as shown in Fig.2. ζ-potential also affects the velocity of the fluid. From the result in Fig.2, we can calculate ζ-potential of electric double layer of the wall by Eq.(1). It is shown in Fig.3.

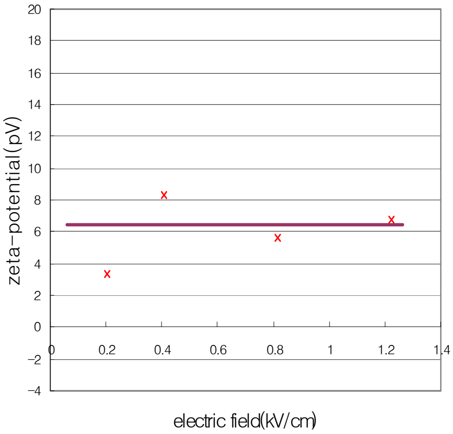

Fig.3 ζ-potential of PDMS channel. ζ-potential is independent with electric field. ϵ of water is 87 F/m at 0℃, 80 F/m at 20 ℃. η of water is 10^{-3}kg/m·sec.

IV. Conclusion

In this research, micro-channel is made of PDMS, which is cheap and ease to handle. And corona discharge is used to change hydrophilicity of PDMS. As a result, micro-channel can easily have negatively charged wall and we can easily generate electroosmotic flow in micro-channel. We also confirm the linear relationship between electric field and flow rate. Finally, ζ-potential can be calculated from electroosmotic flow velocity. Because flow rate becomes larger as electric field gets higher, ζ-potential is independent with electric field.

Acknowledgement

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