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Effect of hydrophilicity on electrically driven flow in microchannels

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Abstract

In this study, the influence of different surface hydrophilicity on flow rate of microchannel was investigated. Rectangular microchannel was made by only PDMS (polydimethylsiloxane). In making microchannel, the patterned PDMS and the bottom PDMS were treated by argon plasma and then coated by allyl alcohol (99%) in the vacuum plasma instrument. PDMS surface contact angle was controlled by the change of power density during the vacuum plasma treatment process. The length and the width of microchannel were changed but the depth of microchannel was fixed at 100 μm. Several different external voltages were applied to investigate the flow rate change in microchannel.

In spite of the channel length change, flow rates of microchannels were practically same at the same electric field. But microchannels, of which PDMS surface contact angles were 20° and 80°, showed different flow rates at the same electric field. Such flow rate difference was explained by relative zeta potential to show the effect of surface hydrophilicity change. This result showed that surface contact angle change affects the flow rate change of fluid in microchannel.

Keywords: PDMS; Rectangular microchannel; Hydrophilicity; Vacuum plasma; Allyl alcohol

1. Introduction

Microfluidic devices can be fabricated from glass, quartz, silicon, etc. However, these materials are expensive and the associated fabrication process is time-consuming, and this has led to intensive exploration for suitable materials [1–3]. Among the methods of fabrication used for microfluidic devices, the soft lithographic method using PDMS (polydimethylsiloxane) has been widely studied, due to its low cost and rapidity [4–8]. However, the conventional PDMS, which has a hydrophobic surface, hinders the transportation of fluid in microchannel. Therefore, it needs to make the hydrophilic surface of PDMS. There are several methods developed for PDMS surface modification. One of them is the oxygen plasma treatment method. In oxygen plasma treatment method, the contact angle of PDMS surface depends on the plasma intensity and the treatment time of instrument [5,6,9]. Following the oxygen plasma treatment, initially hydrophilic PDMS surface becomes increasingly hydrophobic with the increase of aging time. There are several methods of overcoming this problem, such as keeping PDMS in a special environment, rinsing it with a special solution, or coating it with special materials [10–12]. The electro-osmotic flow in microchannel is related to the electric double layer of the solid liquid interface. The electro-osmotic flow can be easily controlled by adjusting the external voltage or pH of solution. For example, if the electric field increases by increasing of external voltage, the flow rate in microchannel increases at the same channel length and the same surface property [7,11,13]. The fluid velocity generated by electro-osmotic flow in microchannel can be observed by using a fluorescent material [14–19].

In this work, we measured the variation of the flow rate in microchannel having different PDMS surface hydrophilicity. We changed PDMS surface contact angles as 20° and 80°. To maintain the surface hydrophilicity of PDMS for a long time, we coated allyl alcohol on PDMS surface before attaching the patterned PDMS and the bottom PDMS. Several different external

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voltages were applied to investigate the flow rate in different electric fields. The flow rate change, which was caused by hydrophilicity difference, was discussed in terms of a relative zeta potential.

2. Experimental procedure

2.1. Microchannel fabrication

First of all, we made a mask having the desired pattern for the fabrication of microchannel, and used a printer with a resolution of 10,000 DPI to print the mask on the film. The depth of microchannel was fixed as 100 μm. The lengths of microchannels were varied from 10 mm to 30 mm to investigate the effect of the length change in microchannel. At each of the two ends of microchannel we made a reservoir with a diameter of 12 mm. Fig. 1 shows the process used for fabrication of microchannels, which is based on the soft lithographic method. After manufacturing the mask, we coated the PR (photoresist) on the silicon wafer (ULTRAPACK Wafershield^{TM}, H9100-0302) treated with HMDS (hydromethyldisiloxane) for 10 min to reduce the resistance between the wafer and the PR. SU-8 100 (Microchem, USA) negative photoresist was used. The speed of the spin coater was controlled in two steps to coat the PR onto the silicon wafer. After depositing the PR coating, the silicon wafer must be soft baked to evaporate the solvent and densify the PR layer. For this purpose, it was baked at 65 °C for 20 min and then baked again at 95 °C for 50 min. Following the process of soft baking, the PR coated silicon wafer was exposed to UV (350 nm) for 3 min, and then baked again at 65 °C for 1 min and then at 95 °C for 12 min. Finally, it was developed, rinsed and dried. The detailed photolithographic method used for the SU-8 PR is given in Table 1. Fig. 2 shows SEM photographs of pattern on silicon wafer. PDMS pattern was acquired by pouring PDMS onto the silicon wafer pattern treated with TMCS (trimethlychlorosilane) for 10 min to separate well PDMS and silicon wafer pattern. After pouring PDMS onto silicon wafer, the silicon wafer was placed in a vacuum-oven for 1 h under a pressure of approximately 0–100 mmHg to remove bubbles, baked for 2 h at 70 °C, and then PDMS pattern was separated. Bottom PDMS was made also by soft lithographic method without mask. PR layer was coated uniformly on silicon wafer, and exposed without mask, and through the later soft lithography process we made a bottom PDMS.

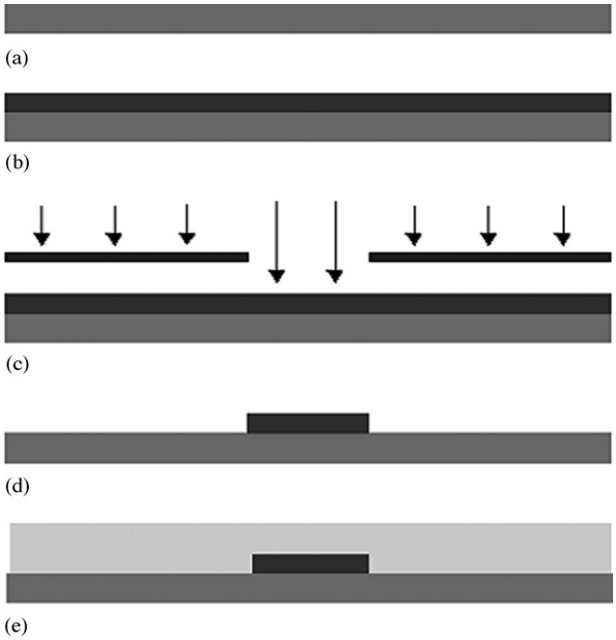

Fig. 1. Fabrication process using soft lithographic method. (a) Silicon wafer, (b) SU-8 coating, (c) UV exposure, (d) SU-8 development and (e) PDMS molding.

Table 1
Photolithographic method for SU-8 photoresist

Step	Process	Method
1	Substrate pretreatment	Treat with HMDS (hydromethyldisiloxane) for 10 min
2	Coating	Step 1: 500 rpm, 30 s; step 2: 2000 rpm, 30 s
3	Soft baking	20 min at 65 °C; 50 min at 95 °C
4	Exposure	3 min
5	Post-exposure baking	1 min at 65 °C, 12 min at 95 °C
6	Development	Develop with SU-8 developer for 10 min
7	Rinsing and drying	Rinse with IPA (isopropyl alcohol), dry with a gentle stream of nitrogen

To make the homogeneous microchannel having same surface characteristic, patterned PDMS and bottom PDMS were treated in the vacuum plasma instrument. Vacuum plasma treatment was carried out as follows. We treated PDMS surface with a power of 50 W for 10 s at the pressure of 1.2×10^{-1} Torr in the argon surroundings and then treated again with 20 W or 80 W at the pressure of 3.0×10^{-1} Torr in allyl alcohol surroundings for 3 min. PDMS surface coated with allyl alcohol showed hydrophilicity. PDMS surface contact angle was about 20° and 80° for the power density of 20 W and 80 W, respectively. We tried two other methods of oxygen plasma and HCl solution treatment to make PDMS surface hydrophilic.

The contact angle of native PDMS was about 105°. The contact angle of PDMS was measured by the FACE CONTACT ANGLE (KYOWA INTERFACE, CA-A). In making microchannel, patterned PDMS and bottom PDMS were attached and heated. Finally, the microchannel system was constructed by connecting the adapter at the both ends of microchannel.

2.2. Experimental method

A buffer solution of pH 7.0 (Weilheim, WTW pH 7.0, Technical buffer 50 ml) was used in microchannel system. The conductivity of the buffer solution was 4.87 mS/cm at the temperature of 25.9 °C and the viscosity was almost same as that of the water. Generally, fluorescent material is used in microchannel system to calculate the fluid velocity. However, in this work, we calculate the flow rate from the weight change of the receiver connected at the end of the adapter. Fig. 3 shows a schematic diagram of the experimental apparatus. The buffer solution was introduced into microchannel by means of a microsyringe. If any bubbles were introduced into microchannel, additional buffer