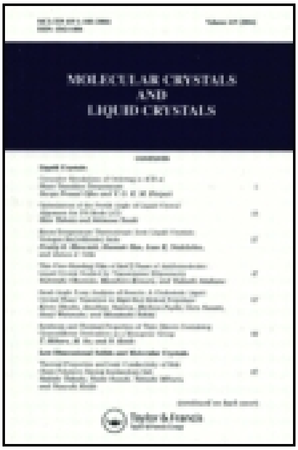

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Surface Modification of Microchannels with Fluorinated Polymer Langmuir-Blodgett Films

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SURFACE MODIFICATION OF MICROCHANNELS WITH FLUORINATED POLYMER LANGMUIR-BLODGETT FILMS

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The Langmuir-Blodgett (LB) technique was utilized to control surface properties of narrow microchannel walls at the molecular scale. Fluorinated amphiphilic polymer (pC7F15MAA) was synthesized and its ultrathin films were prepared by the LB technique. Microchannel was fabricated with glass substrates. A laminar flow of water in hydrophilic and hydrophobic microchannels was monitored in situ using an optical microscope equipped with a digital CCD camera. Shape of meniscus was clearly monitored with 250 ms time-resolution. The fluorinated polymer LB film can be a good candidate to control water motion in the microchannel.

Keywords: Langmuir-Blodgett film; microchannel; microfluidic device; polymer

1. INTRODUCTION

Recently, much attention has been paid to microfluidic devices [1–4]. Microfluidic devices have one or more channels with submillimeter scale. Since they are portable and compact devices, microfluidic devices can be used to obtain fundamental aspects of fluid such as diffusion coefficient, viscosity, and pH. Although the phenomenon occurred in the microchannel have attracted much attention three decades ago [5], the device has

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interesting features for application in bioassays and microreactors. In particular, microfluidic devices are expected to be promising tools for clinical diagnostics.

Manipulating the fluid flow in microchannels is crucial in the design and fabrication of microfluidic devices. For example, surface properties, hydrophilicity and hydrophobicity play an important role on liquid behavior at the micrometer scale. The "bottom up" techniques, such as self-assembled monolayer formation, layer-by-layer deposition, and Langmuir-Blodgett (LB) technique are well known approach to assemble organic ultrathin films at the molecular scale. One advantage of the approach is relied on the fact that various solid substrates can be coated homogeneously at the nanometer scale. These ultrathin films show specific surface properties; hydrophobicity, hydrophilicity, resist, and adhesion, etc. In this paper, we demonstrated surface modification of microfluidic devices with ultrathin polymer LB films [6]. Fluorinated polymer LB films were used for surface modification of microchannel walls (500 mm width). The dynamic behavior of water flow in the microchannel was monitored by an optical microscope equipped with a digital CCD camera.

2. EXPERIMENTAL

We synthesized fluorinated polymer (poly(pentadecafluorooctyl methacrylamide), pC7F15MAA, Fig. 1) by conventional radical polymerization [7]. Briefly, N-1H, 1H pentadecafluorooctyl methacrylamide was synthesized with pentafluorooctyl amine (Daikin Co., Ltd, Japan) and methacryloyl chloride according to a reference. The ultrathin polymer films were fabricated with the LB technique. Surface-pressure area isotherms for the pC7F15MAA monolayer was investigated with an automatically controlled Langmuir trough (FSD-110 and 111, USI). The pC7F15MAA monolayer was transferred onto glass substrates at 30 mN/m and 25°C by a

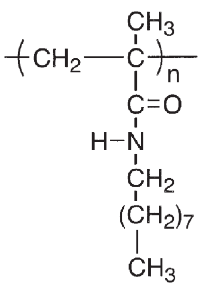

FIGURE 1 Chemical structure of pC7F15MAA.

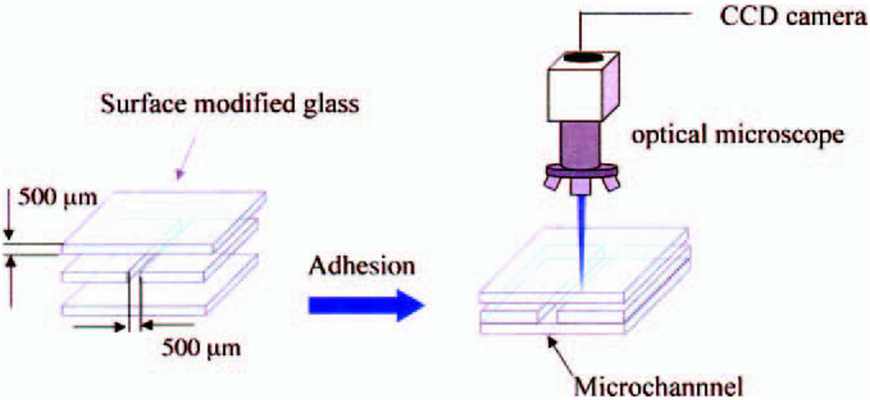

FIGURE 2 Fabrication and microscopic observation of microchannel.

vertical dipping method. The contact angle of water droplet on pC7F15MAA LB films was measured by the sessile drop method with a CA-X contact angle meter (Kyowa Interface Science Co., Ltd). Microchannels were fabricated as follows; the pC7F15MAA LB films with six layers were transferred onto four glass substrates (500 mm thick). The substrates were assembled with UV adhesive (Norland Optical Adhesive 68, Norland Products, Inc.) The substrate edges were aligned and separated by a desired distance (ca. 500 mm, see Fig. 2). A hydrophilic microchannel was also prepared using cleanly washed glass substrates. Distilled water was pumped into the microchannel at the flow rate of 20 ml/min by a micro tube pump (KDS210). An optical microscope (VANOX-T, Olympus) equipped with a digital CCD camera system (C4542-95-12ER, Hamamatsu) was used for the real-time imaging of a water flow. All the measurements were carried out at room temperature.

3. RESULTS AND DISCUSSION

Fluorinated amphiphilic polymer, pC7F15MAA took condensed and stable monolayer formation at the air/water interface. The pC7F15MAA LB films can be transferred onto solid substrates as Y-type LB films with a transfer ratio of almost unity. The LB films showed relatively higher contact angle (114°), lower critical surface tension (12.5 mN/m), and good thermal stability [7]. Figures 3(a) and 3(b) show the shape of water flow for hydrophilic and hydrophobic (six layers of pC7F15MAA LB films) micorchannels, respectively. The channel width was 500 mm and distilled water was

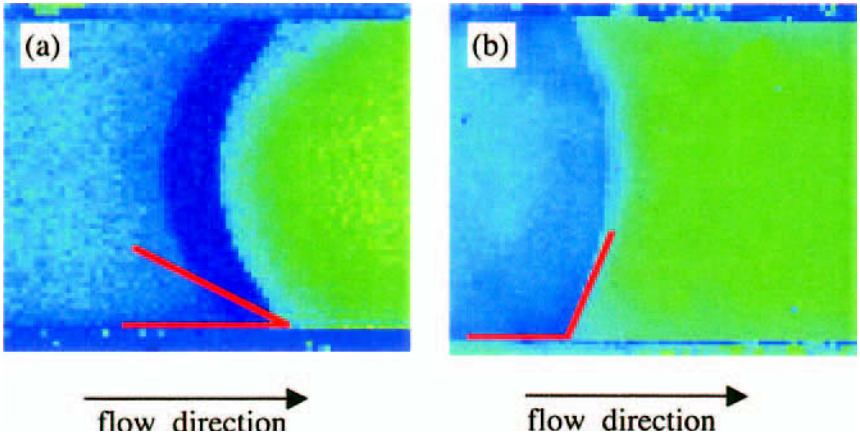

FIGURE 3 Optical micrographs of water flow profile in (a) hydrophilic and (b) hydrophobic (pC7F15MAALB film) microchannels. The channel width was 500 μm.

pumped from left the side in Figures 3(a) and 3(b). Interestingly there are significant differences in the meniscus shape of water. The meniscus takes "U-shape" form in the hydrophilic microchannel, while it shows "convex" meniscus in the hydrophobic microchannel. These figures allow visual characterization of the surface properties in the microchannel. The quantitative analysis for water flow in the surface modified microchannel will be shown is near future.

Figure 4 shows a time-resolved flow profile for the microchannel coated with pC7F15MAA LB films (six layers). No significant changes in the profile were observed in the time regime. This implies that the microchannel walls were uniformly coated with pC7F15MAA LB films.

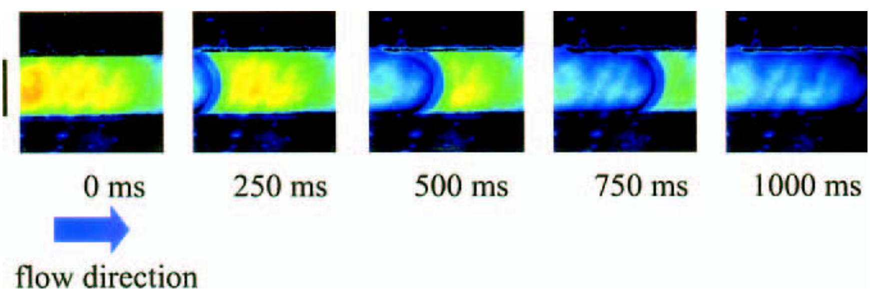

FIGURE 4 Time course of water meniscus profile in the microchannels coated with pC7F15MAALB films (six layers).

The flow rate for water in the microchannel was calculated from these snapshots. The flow in the microchannel can be evaluated by capillary number (Ca) [8];

$$\mathrm{Ca} = \mathrm{U}\eta/\gamma \tag{1}$$

where U is fluid velocity, η is fluid viscosity (1.0×10^{-3} Pa·s), and γ surface tension (72.2×10^{-3} N/m). The Ca value was determined to be 2.2×10^{-5} using Eq. (1), which implies that the experimental data was taken within a laminar water flow condition. This seems to be good agreement with the fact that no changes in the shape of water meniscus occurred during water flow.

In summary, the surface of microchannel was successfully modified with fluorinated polymer LB films. The shape of water flow strongly depends on wetting properties of microchannel walls. Moreover, the shape of air-water interface in motion was characterized with optical microscopy equipped with a digital CCD camera. The dynamic process of water flow can be visualized using this method. The method will be helpful for understanding the relationship between interfacial forces and viscosity at the interface of microchannels.

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