Effect of Sub-Pattern on Guiding Liquid Propagation at Microchannel Junction

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Keywords: sub-pattern, ESEM, microchannel, liquid flow, Young-Laplace equation, pinning effect

Recently, microfluidic devices have been actively studied in varieties of fields such as chemical, biological, and analytical industries [1-3]. The micro channel and tube application are recognized important key technologies. In functional microchannel fabrication, it is required to design some corrugated surfaces or some pillars at an intersection among microchannels. In this regard, environmental scanning electron microscope (ESEM) is an effective system in order to evaluate wetting phenomena in a microstructure. In this paper, we discuss the effects of a pillar type sub-pattern for guiding liquid propagation at the junction of the microchannel by the ESEM observation. On the points of Young-Laplace equation and pinning effect, we focus on the effectiveness of a sub-pattern of controlling the liquid flow in the microchannel network.

In this experiment, V- and T-shaped junctions of microchannel were formed by photolithography. In the V-shaped microchannel fabrication, a glass substrate was cleaned up with organic solvents prior to photolithography. As a channel material, negative type dry film resist (DFR) (NCP250, the Nippon Synthetic Chemical Industry Co., Ltd.) of 50μm thickness was employed. Then, the DFR film was laminated on the glass substrate. Pattern development was carried out by dipping into a sodium hydroxide aqueous solution for 40s. The width and height of the micro channel became 10 and 50 μm, respectively. The corner angle of V-shape channel was 40 degree. In the case of T-shaped microchannel, a Si substrate was cleaned up with organic solvents. The microchannel was formed with SU-8 photoresist (3050, Kayaku Chemical Corp.) by the typical photolithography process. The details of fabrication processes are described in our previous report [3]. The width and height of the channel became 100 and 50 μm, respectively. At the channel junction, a pillar shape sub-pattern was designed at the left side position in the junction. The diameter and height of the pillar were 60 and 50 μm, respectively. The in-situ observations of water condensation and propagation in the V- and T-shaped microchannels were carried out using a ESEM (XL30: Royal Philips). A peltier cooling stage is equipped in order to control the sample temperature around water dew point. The microchannels were cooled at around 0 °C, then relative humidity on the surface of the samples reached to a saturation condition. The vaporized distilled water progressively condense on the whole area of the sample surface.

Figure 1 shows the time-lapse ESEM images of the water propagation in the V-shaped channel. In Fig. 1a, a slight amount of water condensed in the V-shaped corner at which the channel area is relatively wide. Then, the water meniscus forms in the channel and propagates from each side toward the corner as shown in Fig. 1b. In this case, the condensed water at the channel corner was disappeared. Finally, as shown in Fig. 1c, the

![Figure 1](image-url)  
Fig. 1. The water condensation in the V-shaped channel.
whole area of V-shaped channel is filled out with the condensed water. In order to analyze these liquid condensation phenomena, we employ $\Delta P$ defined as a pressure difference across the interface between water and ditch interface as the following well known Young-Laplace equation,

$$\Delta P = 2\gamma/r \tag{1}$$

where a symbol $\gamma$ is surface energy of liquid, $r$ is radius of the a ditch. It is clearly stated that a pressure difference $\Delta P$ becomes large as the channel width becomes narrower. Therefore, the water condensation is more likely occurs in the narrow channel comparing with the wider channel corner as shown in Fig. 1. From this result, the wetting of narrow-width microchannels is faster than that of the wide-width one due to a capillary force in the microchannel. In this regard, it can be considered that the amount of $\Delta P$ became large by forming a sub-pattern in a channel junction because of the decrease of distance between the side walls. Therefore, wetting phenomena act to decrease the amount of $\Delta P$. As shown in the above experiments, it is effective to adjust the channel width for controlling the liquid flow. Therefore, in this regard, we employed a sub-pattern at a T-shaped channel junction which is representative junction design in a functional channel network. Table 1 summarizes the time-lapse ESEM images of the microchannel with a sub-pattern and schematics of them with the passage of time after dewing. As shown in Table 1a, it can be confirmed that a pillar shape sub-pattern isolated on the left side of the junction. At the beginning of the stage (Table 1b, 1c), small amount of water droplets around few micron size is gradually condensed and grown. At the enough time past (Table 1d, 1e), the many droplet grows around 50 $\mu$m. It can be clearly observed that the condensed water is filled out from a side-wall bottom of the channel and propagated along the each side-wall. At last, the most area of sample surface was covered with the condensed water as shown in Table 1e. Noteworthy, around the sub-pattern, the water meniscuses are guided and formed due to the pressure difference $\Delta P$. Particularly, in the left channel bottom, water condensation is noticeable. In Table 1e, the left channel is almost filled up by coalescing the water around the sub-pattern due to the liquid pinning effect. On the contrary, in the right side bottom of the channel junction, a slight dry area can be confirmed because the meniscus condensation around the left side sub-pattern is dominant. The dry area is finally filled up as condensing the surface water.

In conclusion, by the ESEM observation, it is clarified that the sub-pattern is effective to control the liquid flow in the channel junction. These results will contribute to smooth flow at the channel junction in avoid of some trapping factors such as bubble formation.

The authors would like to thank for Mr. H. Endo for the helpful with supporting the experiment. We gratefully appreciate the financial support of NS Promotion Foundation for Science Perception that made it possible to promote my study.

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