GENERATION OF A MICROLIQUID CONCENTRATION SERIES USING WETTABILITY GRADIENT AND ELECTROWETTING

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ABSTRACT

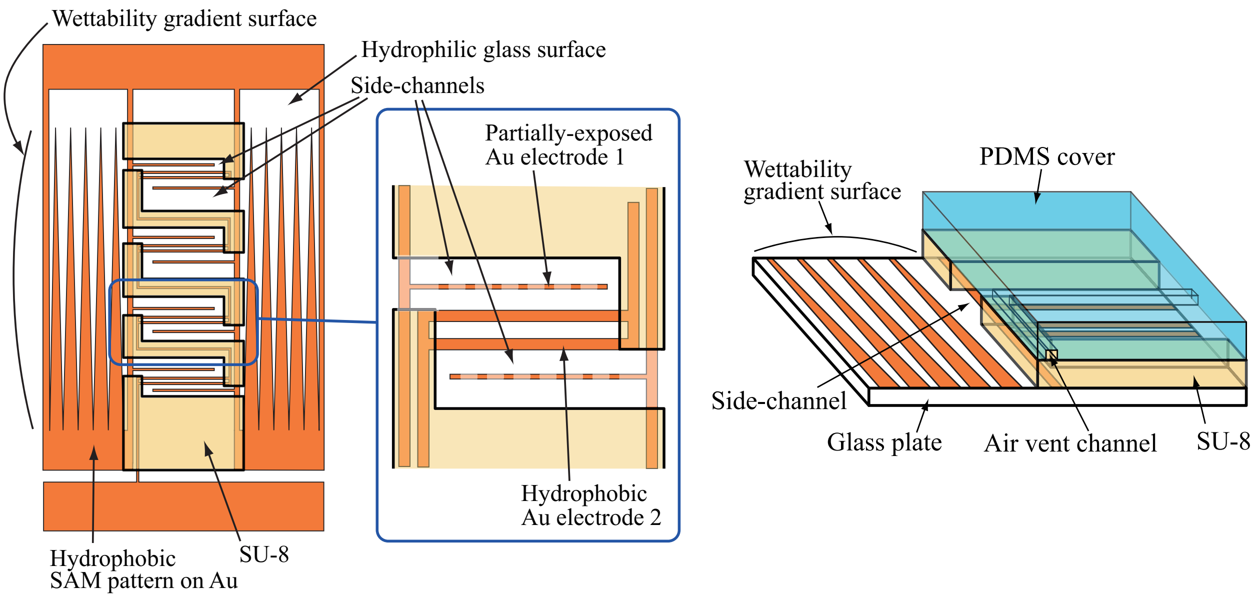
We developed a novel microdevice for generating a concentration series of microliquid mixtures by automatically sampling two different kinds of liquids having multiple different volumes and mixing them at various mixing ratios simultaneously. The present device is operated by automatic droplet transportation technique using a wettability gradient surface and electrowetting-based liquid handling. While a droplet is transported along the wettability gradient, multiple portions of the droplet are drawn into side-channels. Consequently, multiple liquids having different nanoliter volumes (5 to 45 nl) are sampled automatically from two kinds of droplets of microliter volumes. When a voltage is applied between two electrodes, nine pairs of sampled liquids are mixed at different mixing ratios (1:9 to 9:1). The fabricated device was tested using dye solutions, and the average concentrations of prepared mixtures were consistent with expected values at a correlation coefficient of 0.99.

KEYWORDS

Concentration series, Wettability gradient, Electrowetting, Microliquid handling

INTRODUCTION

Microdevices for preparing multiple microliquid mixtures having different concentrations will be quite useful for drug screening, cell analysis with chemical stimulation, calibration in immunoassay, etc. Many microfluidic devices for mixture preparation have already been developed [1-6]. However, these devices require external pressure sources such as a syringe pump and tube connections between devices and these sources. This will highly increase the overall dimension of a microfluidic system, and also make its operation complicated. Moreover, tube connections will increase dead volume in a microfluidic system and need a large volume of redundant liquid sample. In order to solve these problems, we present a microliquid handling technique using automatic droplet transportation on a wettability gradient surface that is sequentially followed by electrowetting-based liquid handling [7]. Our technique requires no pressure sources and no tube connections.



(a) Top view of a device. (Only 4 out of 9 pairs of side-channels are shown here to simplify the schematic.)

(b) Oblique perspective figure of a side-channel and its vicinity.

Figure 1. Schematic of a liquid handling device.

METHODS

The device consists of two wettability gradient surfaces, nine pairs of side-channels, and two Au electrodes (Fig. 1(a)). The wettability gradient surface is created by forming hydrophobic SAMs (self-assembled monolayers), 1-octadecanethiol, on a series of wedge-shaped patterns of Au which are created on a hydrophilic glass plate. The side-channels having hydrophilic bottom surface are fabricated by SU-8 patterning on the glass plate, and covered with a PDMS plate having an air vent channel (Fig. 1(b)). The two hydrophobic electrodes are also made of Au having the same SAMs on it. The electrode 1 which is located at the entrance of a side-channel and longitudinally through it is covered with SiO_2 and partially exposed so that the electrode does not prevent a liquid from being drawn into the side-channel.

Liquid operation will be carried out according to the following procedure. A droplet placed on the hydrophobic area of wettability gradient surface moves toward the hydrophilic area automatically (Fig.2 (a)). During the automatic droplet transportation, multiple portions of the droplet are drawn into side-channels (Fig.2 (b)), and stopped at the edge of the hydrophobic electrode 2. This allows completely independent liquids having side-channel volumes to be stored in the side-channels (Fig.2 (c)). Next, when a voltage is applied between the two electrodes, the liquids break on the electrode 2 by electrowetting, and eventually go across the electrode. Then, the two different liquids from the adjacent side-channels are connected with each other, and multiple mixtures are prepared by diffusive mixing (Fig.2 (d)).

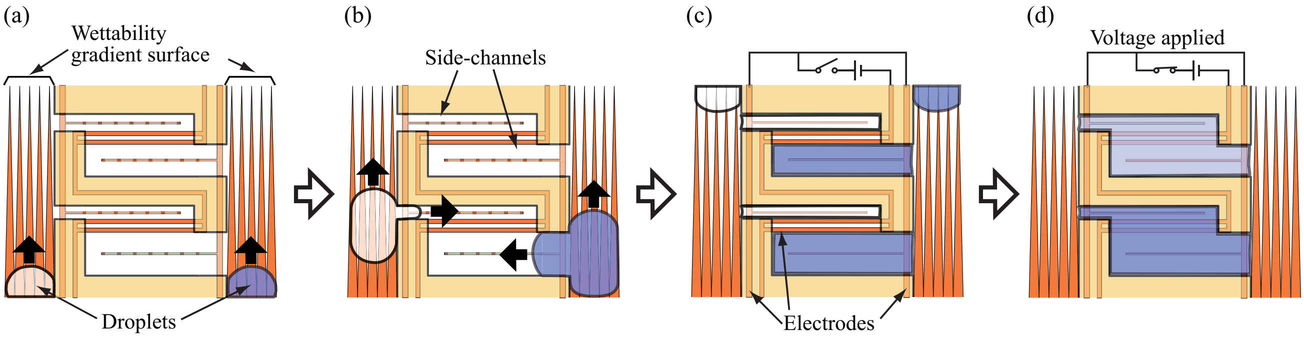


Figure 2. Procedure of mixture preparation.

EXPERIMENTS

Figure 3 shows photographs of the device which was fabricated on a glass plate measuring 3 cm x 3 cm. The two wettability gradient surfaces measure 1.5 cm in length and 5 mm in width. The nine pairs of side channels measure 2 mm in length and 50 µm in depth, and have different widths from 50 µm to 450 µm. A closeup photograph of the side-channels and electrodes is shown in Fig. 4.

A sequential operation was demonstrated using the fabricated device. When two 10 µl droplets of 0.1 M KCl with / without Brilliant Blue FCF dyes were placed on each wettability gradient surface using a pipette, nine liquids having different volumes (5 to 45 nl) were sampled automatically from each droplet (Fig.5 (a)-(c)). Then, when an AC voltage of 5.5 V_{pp} and 10 Hz was applied between the electrodes, the nine pairs of sampled liquids were mixed at different mixing ratios (1:9 to 9:1) (Fig.5 (d)-(f)).

The color density of the mixtures was measured and plotted against the mixing ratio (Fig. 6). Also, the expected line which means the ideal relationship between the mixing ratio and color density of mixtures was obtained from preliminarily-mixed solutions. The average concentrations of the prepared mixtures were consistent with expected values at a correlation coefficient of 0.99.

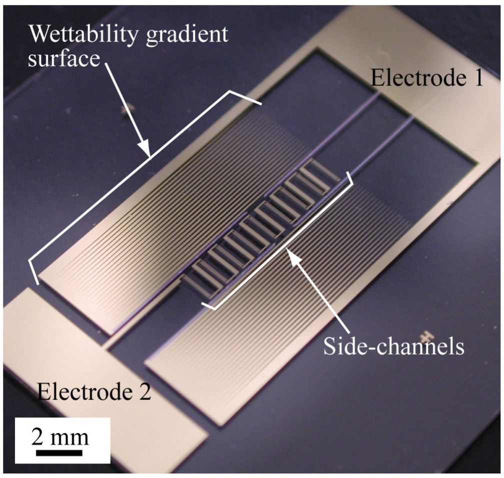


Figure 3. Photograph of the fabricated device.

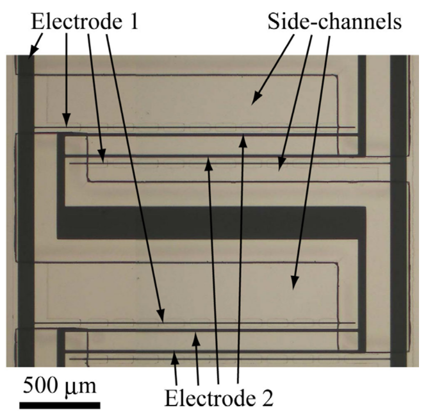


Figure 4. Closeup photograph of side-channels and their vicinity.

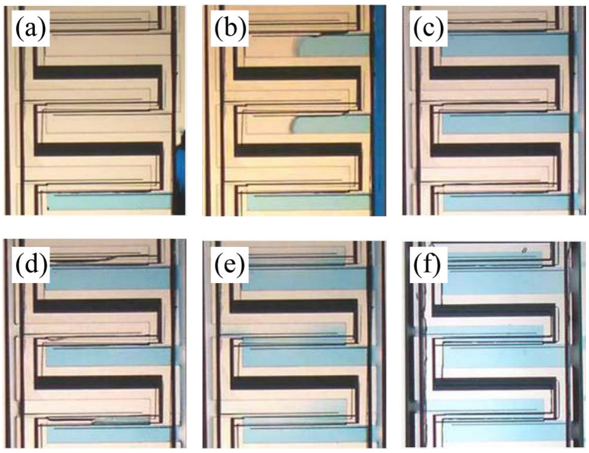


Figure 5. Photographs of sequential operations from microliquid sampling to mixing.

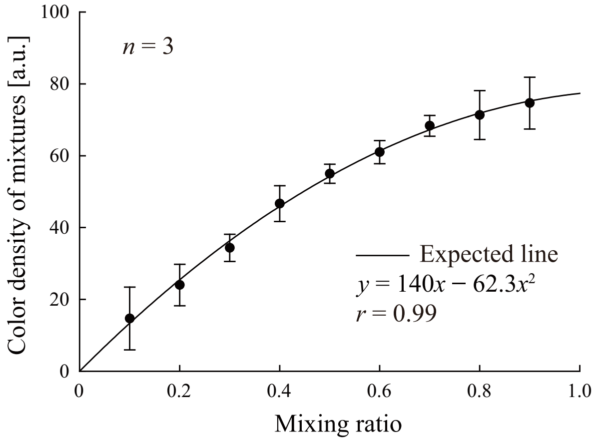


Figure 6. Relationship between mixing ratio and color density of mixtures.

CONCLUSIONS

The fabricated device that doesn't require pressure sources and tube connections succeeded in sampling liquids having different volumes (5 to 45 nl) automatically and preparing nine microliquid samples of different concentrations by mixing two different kinds of liquids at various mixing ratios (1:9 to 9:1). In the near future, we will apply the device to on-site preparation of a calibration curve for point-of-care diagnostics using immunoassay etc.

ACKNOWLEDGMENTS

This work was partly supported by a grant of the Regional Innovation Strategy Support Program of MEXT (The Ministry of Education, Culture, Sports, Science and Technology) in Japan.

REFERENCES

[1] N. Li, C.-H. Hsu, and A. Folch, *Parallel mixing of photolithographically defined nanoliter volumes using elastomeric microvalve arrays*, Electrophoresis, Vol. 26, pp. 3758-3764 (2005)

[2] M. Yamada and M. Seki, *Nanoliter-sized liquid dispenser array for multiple biochemical analysis in microfluidic devices*, Analytical Chemistry, Vol. 76, No. 4, pp. 895-899 (2004)

[3] B.-C. Lin and Y.-C. Su, *On-demand liquid-in-liquid droplet metering and fusion utilizing pneumatically actuated membrane valves*, Journal of Micromechanics and Microengineering, Vol. 18, pp. 1-10 (2008)

[4] H. Bang, S. H. Lim, Y. K. Lee, S. Chung, C. Chung, D.-C. Han, and J. K. Chang, *Serial dilution microchip for cytotoxicity test*, Journal of Micromechanics and Microengineering, Vol. 14, pp. 1165-1170 (2004)

[5] C. Kim, K. Lee, J. H. Kim, K. S. Shin, K.-J. Lee, T. S. Kim, and J. Y. Kang, *A serial dilution microfluidic device using a ladder network generating logarithmic or linear concentrations*, Lab on a Chip, Vol. 8, pp. 473-479 (2008)

[6] K. Hattori, S. Sugiura, and T. Kanamori, *Generation of arbitrary monotonic concentration profiles by a serial dilution microfluidic network composed of microchannels with a high fluidic-resistance ratio*, Lab on a Chip, Vol. 9, pp. 1763-1772 (2009)

[7] T. Yasuda, S. Harada, and K. Daimon, *Microfluidic dispensing device using wettability gradient and electrowetting*, IEEJ Transactions on Sensors and Micromachines, Vol. 128, No. 3, pp. 75-79 (2008)

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