Droplet Movement Induced by Nano Assembled Molecules And Micro Textures

[1,2]Fan-Gang Tseng, and [2] Shu Chun Chien
[1]Engineering and System Science Dept., [2]MEMS Institute
National Tsing Hua University
101, Sec. 2, Kuang Fu Rd., Taiwan, R.O.C , [1]fangang@ess.nthu.edu.tw

ABSTRACT

This paper introduces a droplet movement method on top of a surface prepared by gradient nano-scale self-assembled molecules on micro sized textures. Experimental results demonstrate the contact angles on hydrophobic surfaces without/with micro posts increase from 110° to 143°, while on the hydrophilic surfaces decrease from 56.7° to 12.4°. As a result, the droplet moving speed is increased around twice on the gradient SAM surface with micro structures than that with only SAM gradient or only micro textures.

Keywords: hydrophobicity gradient, Droplet movement, surface tension, thiol SAM's, noano and micro Structures

1. INTRODUCTION

Droplet manipulation has been becoming an emerging alternative to continuous flow systems commonly employed in μTAS for its accurate dose control, less drag force from contact surface, and simpler flow system. Numerous approaches have been developed and tested to transport and manipulate μl-sized liquid droplets moving on the solid surface. The driving mechanisms for moving droplets on solid surfaces include electrostatic actuation [1], light-driven on photoisomerizable monolayer surface [2], the combination of Marogoni flow, capillary flow and phase change [3], and asymmetrically roughed surfaces [4], etc. All these driving forces are related to surface tension heterogeneity, and hysteresis of contact angles. This paper proposes another gentle approach, by employing surface hydrophobicity gradient with micro structured surfaces, to generate much larger surface tension gradient for droplet movement.

2. MATERIAL AND METHOD

2.1 Materials

To prepare gradient SAM's (Self Assembled Monolayers) for the generation of surface hydrophobicity gradient, agarose was botugh from Vegonia, USA, 98％ 1-octadecanethiol and 90% 16-mercaptohexadecanoic was bought from Aldrich, USA, ethanol was bought from Osaka, Japan, and De-ionized water was prepared in the lab.

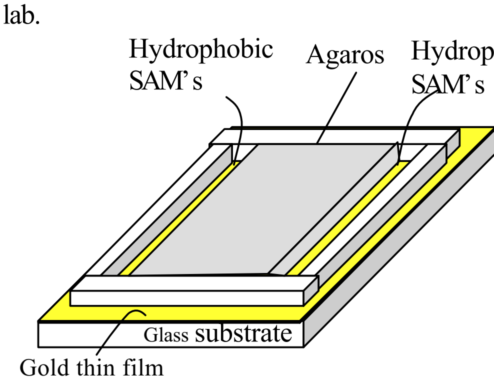


Fig. 1 Fabrication process of hyrophobicity gradient on Au surface by SAMs molecule diffusion

2.2 Gradient SAM's Preparation

The method for generating hydrophobicity

NSTI-Nanotech 2004, www.nsti.org, ISBN 0-9728422-7-6 Vol. 1, 2004

gradient on Au surface, as shown in Fig. 1, employs molecular diffusion inside Agarose gel on the top of Au surface with 1-octadecanethiol (hydrophobic) and 16-mercaptohexadecanoic (hydrophilic) molecules applied on the different side of the liquid reservoir. After 24 hours contact for molecule cross diffusion, the Agarose gel was peeled off from Au surface thus left a hydrophobicity gradient on the surface. [5]

2.3 Fabrication of Micro Structures

In the fabrication of micro structures, SU-8 thick negative tone resist was employed. SU-8 resist was first spun on silicon substrate for 20 µm thick, and then undergo lithography process to define the position and pitch for post arrays. Fabricated micro posts were then coated with 20nm Cr and 100nm Au. The fabricated posts were designed in different diameters (ranging from 30 µm to 100 µm) and pitches (ranging from 30 µm to 180 µm), as shown in Fig. 2. [6]

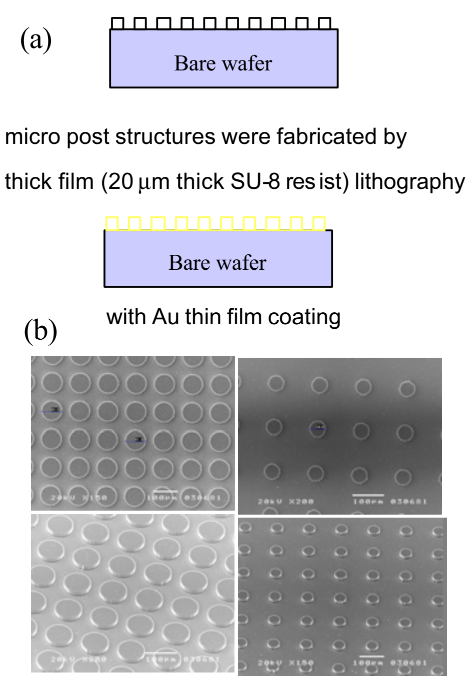
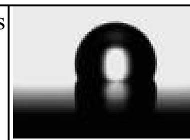
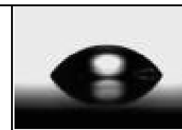
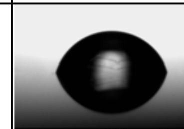
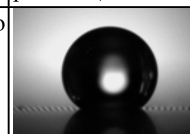


Fig. 2 Micro posts fabricated by thick film lithography(a) Fabrication process (b) SEM picture of Micro posts

(a). Au on glass side+ SAMs	 $\theta = 110.7^\circ$ Hydrophobic SAMs	 $\theta = 56.7^\circ$ Hydrophilic SAMs
(b) Au on micro posts	 $\theta = 109.9^\circ$ dia: 60 μ m pitch:40 μ m	 $\theta = 73.8^\circ$ dia:80 μ m Pitch: 180 μ m
(c) Au on micro posts+SAMs	 $\theta = 143.6^\circ$ Hydrophobic SAMs dia: 60 μ m pitch:40 μ m	 $\theta = 12.4^\circ$ Hydrophilic SAMs dia:80 μ m Pitch: 180 μ m

3. RESULTS AND DISCUSSIONS

To understand contact angle variations for surfaces with different properties, six different surfaces have been prepared, including: (a) pure hydrophobicity gradient on Au surface, (b) micro post with different geometries, and (c) the combination of the above two. The contact angles were measured and tabulated in Fig. 3. When Au surface treated with only pure SAM's of 1-octadecanethiol (hydrophobic) molecules and 16-mercaptohexadecanoic (hydrophilic) molecules, the contact angle is about 110.7° and 56.7°, respectively, very typical for SAM's modified surface (Fig. 3a). In Au on post structures with different sizes and pitches, the maximum and minimum contact angles obtained in this experiment is 109.9° and 73.8°, respectively, not in a wide range as well (Fig. 3b). However in the combination of nano and micro structures, as shown in Fig. 3c, maximum and minimum contact angles can be changed to 143.6° and 12.4°, respectively. This demonstrates a contact angle gradient improvement from 56.7°-110.7° to 12.4°-143.6°, important for long range droplet transportation with high speed.

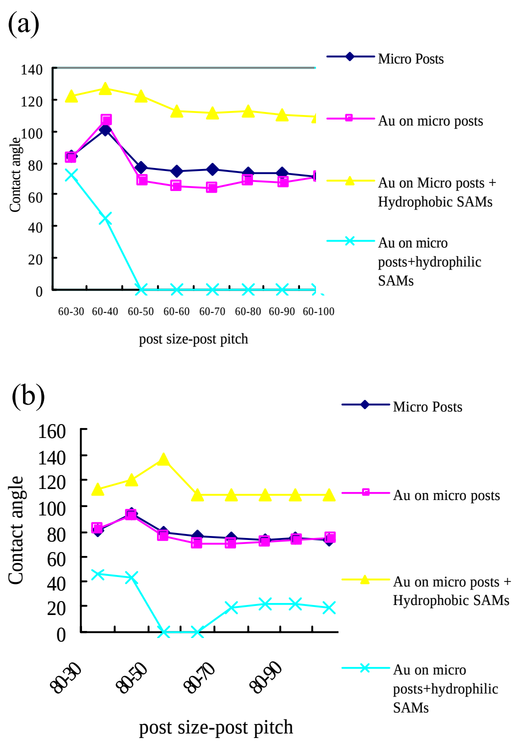


Fig.4 Contact angle variation versus pitch difference for (a) 60 µm posts, and (b) 80 µm posts in different SAM's coatings. Post pitches varied from 30 µm to 100 µm

To figure out the optimum post pitch for contact angle adjustment, 60 µm and 80 µm diameter posts with pitches varied from 30 µm to 100 µm were coated by different SAM's for contact angle measurement, and the results are shown in Fig. 4. In Fig. 4a, the maximum contact angle appears for the 60 µm posts at pitch of 50 µm, while the minimum contact angle happens interestingly at the similar angle. Similar results can be found in Fig. 4b for the 80 µm posts, the maximum and minimum contact angles appear at around 40-50 µm. This suggests that once the pitch is decided, the sizes of posts do not affect contact angles very much. The pitch defines the roughness of the surface.

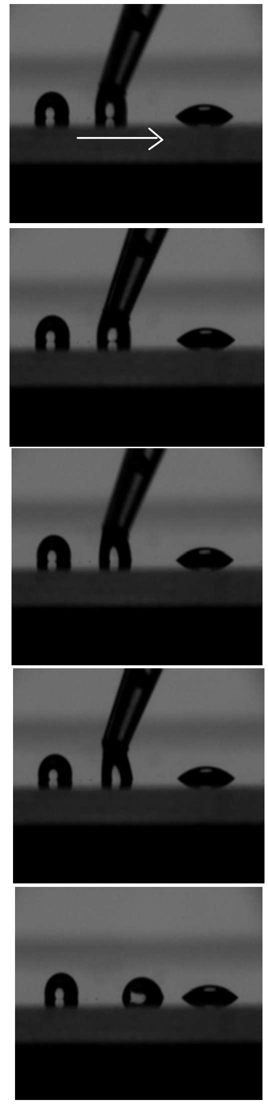


Fig.5 Droplet movement on SAMs/Au surface

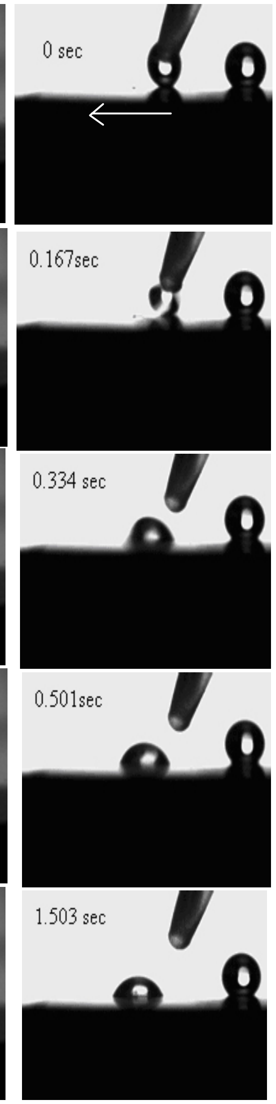


Fig.6 Droplet movement on SAMs/Au/micro post surface

To compare the droplet movement speeds on the 3(a) and 3(c) surfaces, CCD image recording was applied for analyze droplet movement on different surfaces. The time sequences for these two cases are shown in Fig.5 and Fig.6, respectively, and the analyzed positions of droplet geometry center versus time are shown in Fig.7. It demonstrates the average droplet movement speed is around

1.88 mm/sec for the 3(a) surface while 3.26 mm/sec for the 3(c) surface under the same traveling time, almost as twice speed improvement by the combination of both surface hydrophobicity gradient and micro structures.

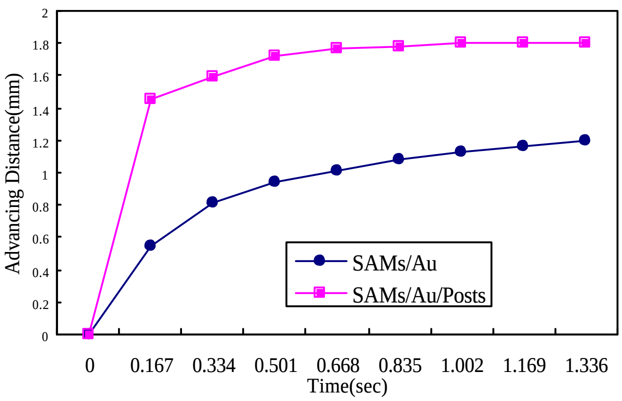


Fig. 7 Droplet movement distance versus time

4. DISCUSSIONS

In this experiment, the surface tension gradient built up by the gradient of SMA's coatings was employed to drive liquid droplet movement. However, most SAM's system can provide only about 60° variation in surface contact angle, not large enough for the droplet driving for long distance. With the assistance of micro structures, the apparent contact of nano SAM' s molecules can be further expands to higher or lower level, thus greatly increases the contact angle gradients, 131.2° in this case, which help droplets more efficiently travel in long distance with higher speed.

5. CONCLSION

In this paper, we propose a novel method by employing both surface hydrophobicity gradient in nano scale, and post structures in micro scale, to enlarge the surface contact angle gradient from 60° to more than 130° for droplet actuation. Experiments have been conducted successfully in the fabrication of this micro/nano structured system, and the testing of the surface contact angles demonstrates a effective contact angle adjustment. Maximum and minimum contact angle conditions have also been found out and applicable to droplet movement. In the droplet actuation experiment, surfaces combined with SAM's coating and Micro posts carry out a droplet speed of 3.26 mm/sec, twice as large of that of the surfaces with only SAM's coatings. This gentle method can be applied to the transportation of bio-fluids, such as RNA or protein, without damage their bioactivities.

References

[1]Lee, J., Moon, H., Fowler, J., Scholllhammer, T. and Kim, CJ, "Electrowetting and Electrowetting -on-Dielectric for Microscale Liquid Handling", Sensors and Actuators A, Vol.95, pp.259-268, 2002

[2] K. Ichimura, S-K Oh, and M. Nakagawa, "Light-Driven Motion of Liquids on a Photorespon -sive Surface", vol.288, June 2, pp.1624-1626, 2000

[3] Daniel, D S., Chaudhury, M.K., and Chen, J.C., "Fast Drop Movements Resulting from the Phase Change on a Gradient Surface" *Science*, Vol. 291, pp 633-636, 2001.

[4] Bo He and Junghoon Lee, "Dynamic Wettability Switching By Surface Roughness Effect",*MEMS'03,* Kyoto, Japan(2003).

[5] Bo Liedberg and Pentti Tengvall, "Molecular Gradients of ω-Substituted Alkanethiols on Gold: Preparation and Characterization", *Langmuir*, **1995**,11,3821-3827.

[6] Susan Daniel, Manoj K. Chaudhury, John C. Chen, "Fast Drop Movements Resulting from the Phase Change on a Gradient Surface", *Science*, **2001**,291,633-636.