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Effects of microstructure geometry and plasma modification on wetting properties of SU-8 surfaces

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ABSTRACT

We describe the wetting properties of various geometric microstructures fabricated with SU-8 (negative photosensitive epoxy resin) and the effects of chemical modification by SF_6 plasma irradiation. Contact angles of water droplets were measured on ten types of microstructures such as circular pillar, square pillar, cross pillar, and mesh pattern fabricated on SU-8 layers. Moreover, these patterned surfaces were chemically modified by fluorine radicals to change their wetting properties. Contours of the water droplets were also examined from not only the side view but also from the bottom view, through the reverse side of the glass substrate, to investigate the wetting properties. Results revealed that the contact angles on the SU-8 surfaces with microstructures increased after SF_6 plasma irradiation because of C–F bond induction. Only in the mesh patterns, which have isolated cavities, the contact angles less increased as a result of the irradiation, in spite of the fact that the wetting state changed from the Wenzel mode to the Cassie-Baxter mode.

1. Introduction

Numerous studies have been performed on moving liquid droplets for applications such as lab-on-a-chip and other micro devices [1–3]. One of the methods used to achieve the movement of liquid droplets involves altering the wetting property of a solid surface [4,5]. It is well known that the wetting property of a solid surface is affected by both its topographic structure and chemical property.

Early works on the modeling of wetting of liquid drops on rough surfaces have been presented by Wenzel and Cassie-Baxter [6,7]. Wenzel described the contact angle θ_w at a rough surface as follows:

$$\begin{aligned} \cos\theta_w &= r\cos\theta_e \\ r &= (b^2 + 4ah)/b^2 \text{ (for square cross section pillar)} \end{aligned} \tag{1}$$

(a: pillar width, b: pillar pitch, h: pillar height)where r is the roughness factor defined as the ratio of the actual area of the rough surface to the projected area, and θ_e is the contact angle on a flat surface. In this case, the rough surface is completely wetted with a liquid droplet, and this is known as the Wenzel model. On the other hand, Cassie and Baxter described the contact angle θ_c on a rough surface as follows:

$$\begin{aligned} \cos\theta_c &= f\cos\theta_e + f - 1 \\ f &= a^2/b^2 \text{ (for square cross section pillar)} \end{aligned} \tag{2}$$

where f is the surface fraction defined as the ratio of the top surface area to the projected area. In this case, a liquid droplet sits on a composite surface consisting of a solid surface and air, which is known as the Cassie-Baxter model.

Recently, the super-hydrophobic surfaces, which are a combination of a microstructure and a low energy surface, were realized [8,9]. Most of these studies focused on the contact angle, but did not consider the contour of the liquid–solid interface.

In this paper, we describe the wetting properties of pure water on various geometric microstructures fabricated with SU-8 (negative photosensitive epoxy resin) and the effects of chemical modification by SF_6 plasma irradiation.

2. Experimental

Fig. 1 shows the geometry of the designed periodic microstructures, and Table 1 shows their dimensions and surface fractions. Ten types of microstructures were designed and classified into five types: circular pillar, square pillar, cross pillar, cross pillar with hexagonal distribution, and mesh pattern.

Microstructures were fabricated using SU-8 (Microchem 3025) on borosilicate glass substrates. A SU-8 layer, about

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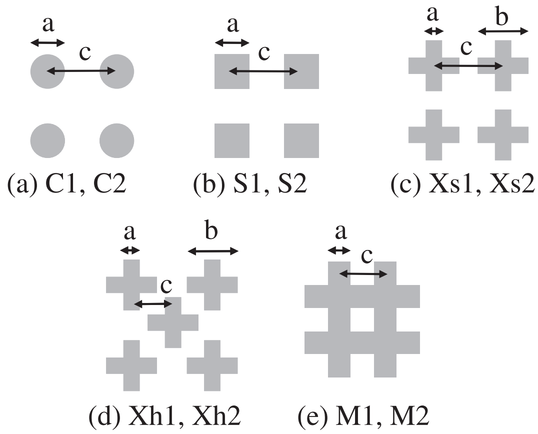

Fig. 1. Schematic diagrams of geometry of designed periodic microstructure. (a) Circle, (b) Square, (c) Cross with square distribution, (d) Cross with hexagonal distribution, (e) Mesh.

3 μm thick, was first coated on the substrate as an adhesion layer. Then a 10 μm thick layer of SU-8 was coated and microstructures were fabricated by UV-photolithography. Chemical modification was performed by plasma irradiation under 10 sccm SF_6 flow, 6.5 Pa pressure, 100 W RF power, and 5 min irradiation time.

Chemical compositions of the flat SU-8 surfaces with and without chemical modification were examined by X-ray photoelectron spectroscopy (XPS). The wetting property of the water droplet was examined by supplying 5 μL deionized water to the SU-8 surface with a micropipette. The contact angle was determined from the side view of the droplet contour by ellipsoidal approximation. The contour of the liquid–solid interface was observed from below through the glass substrate and the SU-8 layer.

Table 1
Dimensions of designed microstructures.

Name	Cross section	Distribution	a (μm)	b (μm)	c (μm)	h (μm)	Surface fraction
C1	Circle	Square	10	–	20	10	0.2
S1	Square	Square	10	–	20	10	0.25
Xs1	Cross	Square	5	25	30	10	0.25
Xh1	Cross	Hexagonal	5	25	22	10	0.25
M1	Mesh	Square	5	–	37	10	0.25
C2	Circle	Square	10	–	30	10	0.08
S2	Square	Square	10	–	30	10	0.11
Xs2	Cross	Square	5	30	50	10	0.11
Xh2	Cross	Hexagonal	5	30	37	10	0.11
M2	Mesh	Square	5	–	87	10	0.11

h: pattern height.

3. Results and discussion

Fig. 2 shows the SEM photographs of the fabricated SU-8 microstructures with C1, S1, Xh1, and M1. From these SEM images, each pillar shape was precisely transferred from the chrome mask pattern, except the concave corners of the cross pillar and mesh pattern. The SEM photographs of the low surface fraction patterns such as C2, S2, Xs2, Xh2, and M2 showed similar to these high surface fraction patterns.

Fig. 3 shows the XPS spectra and AFM images of the SU-8 surfaces with and without plasma modification. The survey spectrum with plasma modification indicates a sharp peak of F1s in contrast to the spectrum without modification. The detail spectra of C1s revealed that the C–F chemical bonds were induced in the SU-8 surfaces after SF_6 plasma irradiation. This chemical modification caused a decrease in the surface energy and an increase in the contact angle of water droplets. From the AFM images, it is clear that the roughness of the surface with plasma modification is almost identical that of the surface without plasma modification,

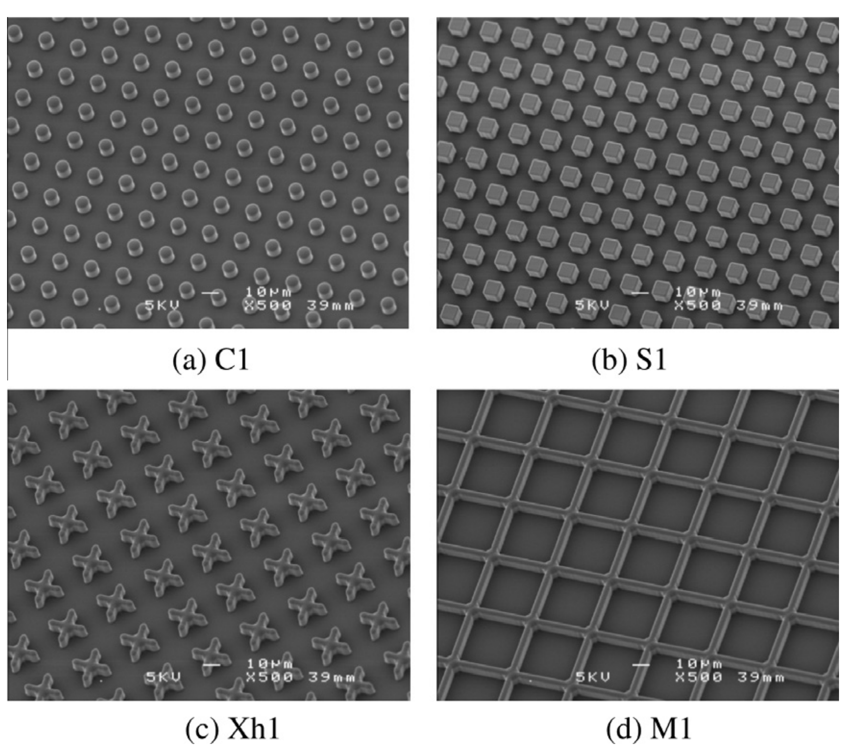

Fig. 2. SEM photographs of fabricated SU-8 microstructures.