THIN FILM PARTIALLY ATTACHED ONTO ELASTOMER SUBSTRATE FOR THREE-DIMENSIONAL MICROSTRUCTURE

A. Takei[1], M. Murano[2], M. Tani[3], H. Fujita[4] and K. Okumura[1,2,3]
[1]Center for Soft Matter Physics, Ochanomizu University
2-1-1 Otsuka Bunkyo, Tokyo 112-8610, Japan
[2]Department of Physics, The Division of Advanced Sciences,
Graduate School of Humanities of Sciences, Ochanomizu University
2-1-1 Otsuka Bunkyo, Tokyo 112-8610, Japan
[3]Faculty of Core Research, Ochanomizu University
2-1-1 Otsuka Bunkyo, Tokyo 112-8610, Japan
[4]Institute of Industrial Science, The University of Tokyo
4-6-1 Komaba, Meguro, Tokyo, JAPAN
e-mail: takei.atsushi@ocha.ac.jp

ABSTRACT

This paper presents a new method for making three-dimensional structure on the surface of an elastomer substrate. In general, micromachining based on lithography process is layer-by-layer fabrication, and the resulting structure is restricted to be two-dimensional. In this paper, we presented that three-dimensional structures were achieved by attaching a thin film partially onto an elastomer. Under compression, the thin films deformed out-of-plane and formed three-dimensional structures. Details of the fabrication process and the fabricated microstructures are presented.

INTRODUCTION

This paper is a contribution to MEMS community to produce microstructures. Previously, lithography-based micromachining (*i.e.* photoresist coating and reactive ion etching process) has been successfully used for making microstructures such as micropillars and grooves made of silicon[1,2]. However, the aspect ratio of width and height of the structure made with conventional micromachining is still a challenging issue. Especially a thin-film three-dimensional structure is hard to make at micro-scale. To overcome this limit, previously, several methods were proposed. For example, liquid surface tension has been used to make thin-film three-dimensional microstructures as reviewed in Ref.[3]. In this method, two-dimensional structures having hinges are made on a silicon wafer, then the structure is bent vertically to make three-dimensional structures by placing liquid droplets near the hinges. Another approach for making thin-film three-dimensional structures was previously presented by Shimoyama's group[4]. In this method, as in the method using surface tension, firstly, two-dimensional structures having hinges are made on a silicon wafer. Then, ferromagnetic (nickel) layers are patterned on the two-dimensional structures. By applying the magnetic field, the two-dimensional structures are bent vertically and the three-dimensional structures are achieved. Although both methods based on surface tension and magnetic field can achieve three-dimensional microstructures, these methods require complicated fabrication processes such as precise liquid placing and ferromagnetic layer patterning.

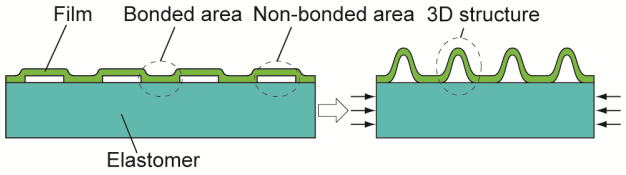

Figure 1 *Concept of proposed method: Thin film is partially attached on an elastomer substrate. By applying compressive strain to the thin-film/elastomer bilayer system, the thin film buckles and forms three-dimensional structure. By arranging the shape of attached films and their bonded/non-bonded areas, the resulting 3D structure can be designed.*

On the other hand, recently, three-dimensional structures made of a sheet with cut patterns attract an attention both theoretically[5] and experimentally[6]. Applying strain to a sheet with cut patterns, the sheet often deforms out-of-plane and forms a three-dimensional structure. This phenomenon occurs at multi-length-scale and observed from cm scale to μm scale. Inspired by the phenomena, we attached a μm-thick film with □m cut patterns partially onto an elastomer. By applying strain to the thin-film/elastomer bilayer system, we achieved a thin-film three-dimensional structure as shown in Figure 1. In this paper, details of the fabrication method are presented, and how resulting structures of bilayer systems with simple Parylene film are different from those with alminium/Parylene composite film is experimentally studied. The three-dimensional structures made with our proposed method are composed of the thin films and elastomer substrate, whereas the three-dimensional structures demonstrated in the previous studies[3,4] were made of silicon wafer. Thus, the present method is useful to create a flexible thin-film three-dimensional microstructures in a simple and inexpensive manner.

FABRICATION AND RESULT

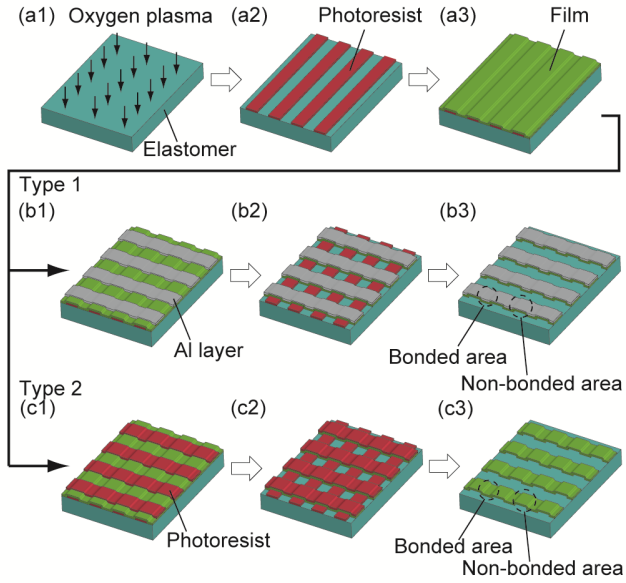

Figure 2 *Fabrication process of the present method: Two different types of fabrication process are presented. (a1) First, elastomer (PDMS) substrate is prepared, and oxygen plasma is applied to the surface. (a2) Photoresist is spin-coated and patterned by photolithography. The plasma treatment in the previous step is required for the spin-coating in this step. The surface is rinsed with HF. (a3) Thin film is deposited onto the entire surface. (b) For type 1, (b1) aluminium layer is deposited and patterned by photolithography. (b2) The part of the thin film not covered with the Al layer is etched by oxygen plasma. (b3) The photoresist layer is removed by aceton. (c1-3) For type 2, photoresist is used to protect partially the thin film from etching. In this case, the photoresist on the top is also removed by aceton. The part of film deposited onto the first set of the photoresist forms non-bonded areas, whereas the part of film deposited onto PDMS forms bonded-areas.*

Figure 2 shows details of the fabrication method. Our proposed microstructure is composed of thin films and an elastomer substrate. To handle the components during fabrication processes, the structure was made on a glass wafer and removed from the glass wafer. Firstly, CYTOP (an amorphous fluorocarbon polymer, Asahi Glass Co., Ltd.) was spin-coated at 3000 rpm for 30 seconds on a (5cm x 6cm) glass wafer and cured at 180 degrees centigrade on a hot plate. This process makes the surface of the glass wafer hydrophobic and reduces the adhesion between the wafer and the elastomer substrate for the removal. For the elastomer, Polydimethylsiloxane (PDMS, Sylgard 184, Dow Corning, Corp., Midland, MI, USA) was used. PDMS was spin-coated at 300 rpm for 30 seconds on the glass and cured at 75 degrees centigrade for 2 hours. The resulting thickness of the PDMS substrate was 300 mm. The base:catalyst ratio of the used

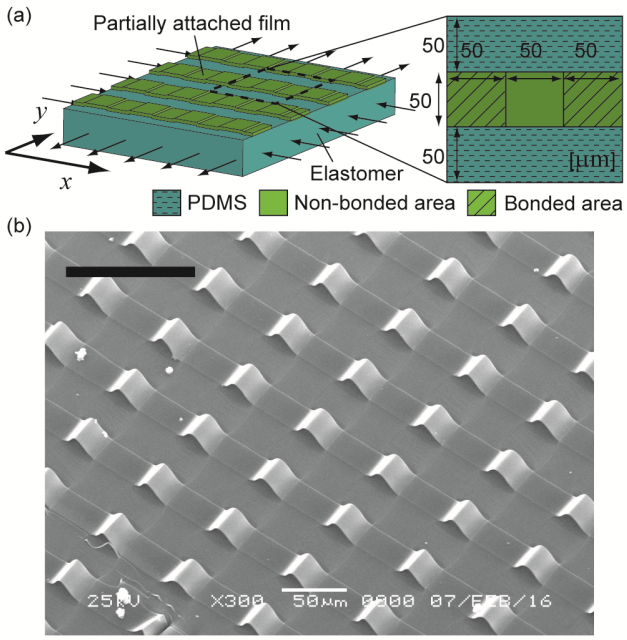

Figure 3 *Fabricated 3D structure: (a) Design and (b) SEM photograph. Thin-film ribbons were attached in 50-μm line and space. Non-bonded and bonded areas were made every 50 μm. Compressive strain was induced by stretching the bilayer system in the y-direction. Due to the volume conservation, the bilayer system was compressed in the x-direction. Consequently, the ribbons buckled and forms a micro-tunnel structure. The scale bar indicates 100 μm.*

PDMS was 10:1 and 30:1, and their shear modulus are 0.27 MPa and 0.04 MPa, respectively, according to our previous work[7]. Oxygen plasma was applied to the surface (at 100 sccm, 20W, 20 Pa, and 30 sec) (Figure 2.a1). Then, adhesive promoter, OAP (Tokyo Ohka Kogyo Co., Ltd.), and photoresist were spin-coated and cured at 110 degrees centigrade on a hot plate. The photoresist layer was patterned by lithography (Figure 2.a2). After the patterning, the elastomer was rinsed with Buffered HF to remove the nm-thick SiO_2 on the surface produced secondarily by the oxygen plasma treatment. A layer of Parylene C (plastic material, Specialty Coating Systems) was deposited on the surface by using chemical vapor deposition (Figure 2.a3). Adhesion between SiO_2 and Parylene is poor, and the SiO_2 layer should be removed by HF before the Parylene attachment. For the patterning of the thin film, a protecting layer of 50 nm-thick aluminium (type 1) or photoresist (type 2) was deposited. For type 1, firstly, the aluminium layer was patterned by wet-etching (Figure 2.b1). On the other hand, for type 2, the photoresist layer was patterned as well as the first set of the photoresist layer (Figure 2.c1). The part of the thin film deposited to the first set of the photoresist layers was not bonded to the PDMS surface, while the rest of the film was bonded. The thin film was etched by oxygen plasma (at 100 sccm, 50W, 20 Pa, and 6 min) (Figure 2.b2 and c2). As the oxygen plasma etches also the photoresist

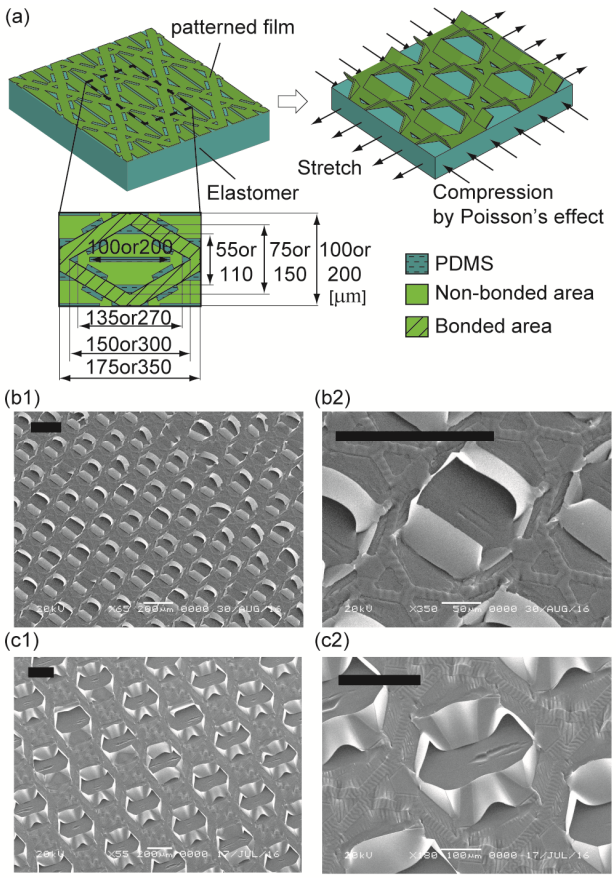

Figure 4 *Another 3D structure made with the proposed method: (a) Design and schematic. (b) With the method type 1 (aluminium/Parylene composite), the film formed the structure as shown in (b1) an SEM photograph and (b2) a magnified photograph. (c) With the method type 2 (only Parylene film), the film was partially attached to the elastomer substrate as shown in (c1) an SEM photograph and (c2) a magnified photograph. The scale bars indicate 200 μm.*

layer, the protecting photoresist was coated with a thickness that is enough to resist the plasma etch. The photoresist layers were removed by aceton, and the bilayer system was rinsed with ethanol (Figure 2.b3 and c3). Finally, the thin film/elastomer structure was cut into 1 cm x 5 cm strip and removed from the glass substrate. As demonstrated later in this paper, thin films and its bonded/non-bonded areas can be patterned in desired shapes, leading to the creation of complex three-dimensional structures.

Figure 3 shows three-dimensional structures made with thin film ribbons partially attached onto an elastomer substrate. Aluminium/Parylene composite ribbons of 50 μm were attached onto the elastomer every 50 μm in the longitudinal direction (Figure 3.a). By stretching the bilayer system in the width direction of the ribbons, compressive strain was applied in the longitudinal direction. The non-bonded parts of the ribbon were bent, and the micro-tunnel structure was achieved.

Finally, figure 4 shows that our method can be used for the creation of complex three dimensional structures. Thin film and bonded/non-bonded area were patterned as shown in figure 4a, and the bilayer system was compressed by stretching. In this experiment, bilayer system was made with the type 1 or type 2 method. For type 1, the thin films formed open-box structure. On the other hand, for type 2, the films of non-bonded area were partially attached to the elastomer and formed in the different shape (we assume that the difference is caused by the electrostatic force between the elastomer and film).

CONCLUSION

In this paper, we proposed a new route to the creation of thin-film three-dimensional structures in a simple manner. By attaching 1μm-thick films with μm cut patterns partially onto an elastomer, 100μm-scale thin-film three-dimensional structures were achieved. Microstructured surfaces often exhibit functionalities such as hydrophobicity[8], smart adhesion[9] and antifogging[10]. We expect that our method opens a new way to create functional surfaces.

ACKNOWLEDGEMENT

This research was partly supported by ImPACT program of council for science, Technology and Innovation (Cabinet office government of Japan). This work was partially supported by a Grant-in-Aid for JSPS Fellows (Grant numbers 16J00871 and 15J10394). We made the photomasks on the University of Tokyo VLSI Design and Education Center's (VDEC) 8-in. EB writer F5112+ VD01, donated by the ADVANTEST corporation.

REFERENCES

[1] C. H. Choi *et al*., "Fabrication of a Dense Array of Tall Nanostructures over a Large Sample Area with Sidewall Profile and Tip Sharpness Control," *Nanotechnology*, 17, pp. 5326-5333, 2006

[2] Y. Q. Fu *et al*., "Deep Reactive Ion Etching as a Toll for Nanostructure Fabrication," *J. Vac. Sci. Technol. B*, 27, pp. 1520-1526, 2009

[3] R. R. A. Syms *et al*., "Surface Tension-Powered Self-Assembly of Microstructures—The State-of-the-Art," *Journal of Microelectromechanical Systems*, 4, pp. 387-417, 2003

[4] E. Iwase *et al*., "A Design Method for Out-of-Plane Structures by Multi-Step Magnetic Self-Assembly," *Sensors and Actuators A*, 127, pp. 310-315, 2006

[5] M. Isobe *et al*., "Initial Rigid Response and Softening Transition of Highly Stretchable Kirigami Sheet Materials," *Scientific Reports*, 6, 24758, 2016

[6] M. K. Blees *et al*., "Graphene Kirigami," *Nature*, 524, pp. 204-207, 2015

[7] A. Takei *et al*., "High-Aspect-Ratio Ridge Structures Induced by Plastic Deformation as a Novel Microfabrication Technique," *Applied Materials & Interfaces*, 8, pp. 24230-24237, 2016

[8] J. Bico *et al*., "Pearl Drops," *Europhysics Letters*, 47, pp. 204-207, 1999

[9] E. P. Chan *et al*., "Surface Wrinkles for Smart Adhesion," *Advanced Materials*, 20, pp. 711-716, 2008

[10] X. Gao *et al.,* "The Dry-Style Antifogging Properties of Mosquito Compound Eyes and Artificial Analogues Prepared by Soft Lithography," *Advanced Materials*, 19, pp. 2213-2217, 2008