

Replication of micro/nano combined structure using micro/nano combined aluminum stamp

Kyoung Je Cha* and Tai Hun Kwon*

* Department of Mechanical Engineering, POSTECH, KOREA

ABSTRACT

This paper presents an easy and efficient fabrication method of plastic replicas of micro/nano combined structure (MNCS) using an aluminum stamp with micro/nano combined structure (ASMNCS) on its surface. ASMNCS could be fabricated by two steps: i) the first step is to introduce micro patterns on an electro-polished aluminum plate by pressing it by micro structured stamp; ii) the second one is to form nano dimple array onto the micro structured aluminum plate making use of the anodic aluminum oxide (AAO) technique. MNCS is successfully replicated on the polymer films via hot embossing process using ASMNCS as a mold. Experimental measurement of contact angle indicates that MNCS in so fabricated film increases the hydrophobicity over the surface which has just microstructure only.

Keywords: Micro/nano combined structure (MNCS), aluminum stamp with micro/nano combined structure (ASMNCS), anodic aluminum oxide (AAO), hot embossing, contact angle

1 INTRODUCTION

In recent years, the need of micro/nano combined patterns draws many researchers' attention. These micro/nano combined patterns have many interesting phenomena, i.e. self cleaning, water-repellency, adhesion-enhancement, optical effect, drag reduction and so on [1]. These micro/nano combined patterns could be applied to micro fluidic devices, micro optical devices and molecular diagnosis [2].

Fabrications of micro/nano combined pattern require not only MEMS but also NEMS technologies [3]. In general, patterning techniques can be categorized into two methods: top-down approach and bottom-up approach [4]. The top-down approaches often use the traditional micro fabrication methods. Photolithography and ink-jet printing belong to this category. Bottom-up approaches, in contrast, use the chemical properties of single molecules to cause single-molecule components to automatically arrange themselves into some useful conformation. These approaches utilize the concepts of molecular self-assembly and molecular recognition [4]. The precision of top-down approaches has its limit. On the other hand, bottom-up approaches could

easily make structures below several tens nano meter, but with a weakness in its productivity.

In this regard, we present an easy and efficient fabrication method of plastic replicas of MNCS. The proposed method merges the top-down and bottom-up approaches in fabricating ASMNCS. Micro patterns were formed on an aluminum plate by pressing it by micro structured stamp. And nano dimple array was subsequently formed onto the micro structured Al plate by AAO technique [5]. Then the micro/nano combined structure is replicated on the polymer film via hot embossing process using ASMNCS as a mold.

We have investigated the effect of hot embossing pressure on the transcriptability in hot embossing process and characterized the hydrophobicity of so fabricated MNCS film by measuring the contact angle.

2 FABRICATION METHOD

Figure 1 schematically shows the overall fabrication method of ASMNCS and polymeric replica.

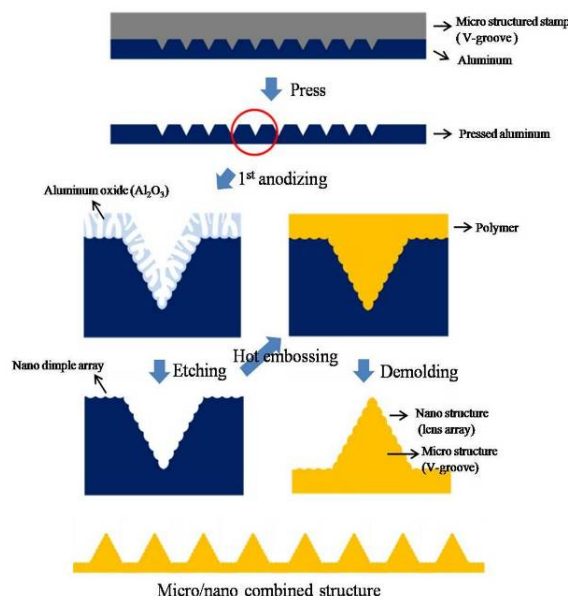


Figure1. Schematic diagram representing the overall fabrication procedure of micro/nano combined aluminum stamp and the replication of polymeric film.

3 FABRICATION AND EXPERIMENT

3.1 Fabrication of micro stamp

In the present work, as an illustration of the proposed method, a microscale V-groove patterned nickel stamp ($2 \times 2\text{cm}^2$) is prepared by nickel electroforming as the micro structured stamp. Figure 2(a) shows the fabrication procedure for the nickel stamp. First, the microscale V-groove patterns were fabricated by well-known Si anisotropic wet etching [6]. The Ni layer (100nm thick) is deposited on the etched Si wafer using E-beam evaporator as a seed layer for the electroforming. Figure 2(b) shows the nickel stamp of which the SEM image is shown in Fig.2(c).

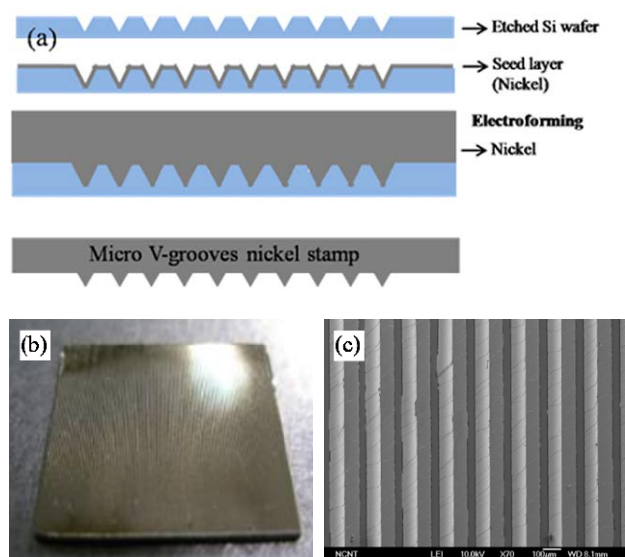


Figure 2. Images of (a) schematic representation of fabrication process for micro scale nickel stamp, (b) actual micro V groove nickel stamp and (c) SEM image of a micro V grooves nickel stamp's surface (width: $164\mu\text{m}$, space: $39.6\mu\text{m}$).

3.2 Fabrication of micro/nano structured stamp

A pure aluminum plate (99.999%) was electropolished in a mixture of ethanol and perchloric acid to remove surface irregularities. An electro polished aluminum plate is pressed by a micro stamp such that the negative pattern is replicated onto the surface of the aluminum plate.

The anodic aluminum oxide (AAO) technique is applied on the micro structured aluminum plate in the following manner. Micro V-groove patterned aluminum plate was anodized at 180V in 0.1M phosphoric acid at -5°C for 12hours. Figure 3 shows cross-section image of the

anodized aluminum template. The anodic porous alumina was formed on inclined surface as well as flat surface.

After the anodization was complete, the formed aluminum oxide is removed in a mixture of 1.8% chromic acid and 6wt% phosphoric acid at 65°C for 8hours. Figure 4(a) ~ (d) show the SEM images of the aluminum stamp's surface. Figure 4(a), (b), (c) and (d) show that ASMNCs was successfully fabricated. It may be noted that nano dimple arrays (inter pore size: 400nm) are uniformly patterned on the microscale V-grooves surface and edge portion as well as on the flat surface.

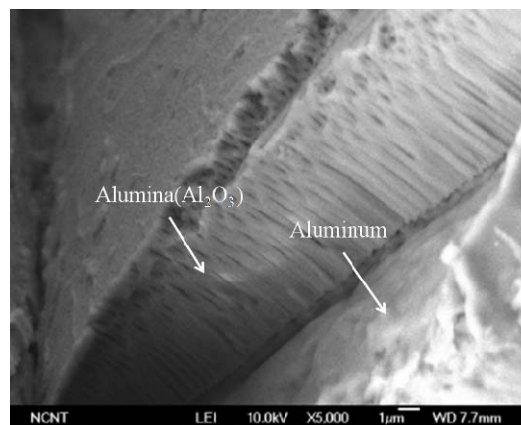


Figure 3. SEM image of anodic porous alumina on inclined surface.

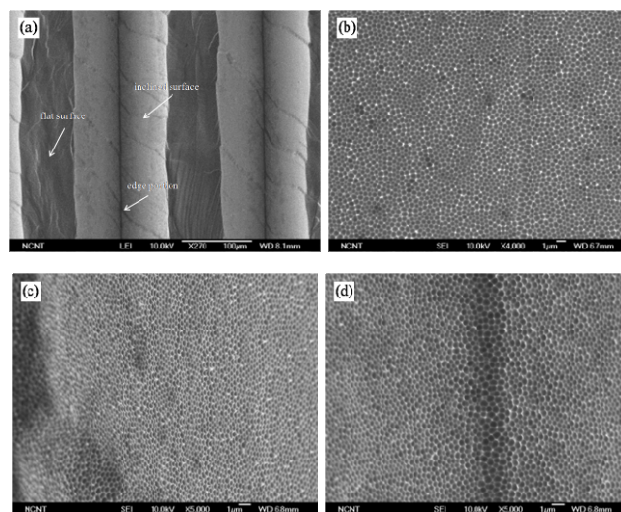


Figure 4. SEM image of fabricated micro/nano combined stamp: (a) stamp's several portions, (b) flat portion, (c) inclined portion and (d) edge portion.

3.3 Replication of micro/nano combined structure via hot embossing

The primary aims of this study are to fabricate an Al stamp with MNCS and to replicate MNCS on polymeric film using Al stamp as a mold via hot embossing. For this study, our group designed and constructed the hot embossing equipment. PMMA films were embossed by different embossing pressures to investigate its effect on the transcriptability. And COC films were used to check the hydrophobicity by means of contact angle. Processing conditions of hot embossing process are summarized in Table 1.

Table 1. Processing condition of hot embossing process

	PMMA	COC
Embossing temp. (°C)	130	140
Holding time (min)	10	10
Pressure (MPa)	22	36.6
	22	21.6

3.4 Measurement of contact angle

Contact angle could be measured to characterize property of micro/nano combined structure. So we measured contact angles of COC films of three kinds: the first with MNCS, the second with only micro V-groove structure and the third with no structure (i.e. just a flat surface). In the case of V-grooves, contact angle was measured in two directions: one along the V-groove direction (say, longitudinal direction), the other transversal direction. Contact angle was measured by a commercial contact meter (DSA100, Krüss Drop shape analysis system). The volume of water droplet used for the measurements was 5 μ l. Contact angle was measured at three different positions for each sample and average values were calculated.

4 RESULT

4.1 Hot embossing

Figure 5 and 6 show SEM images of the replicated PMMA films at several locations. It has been found that micro V-grooves pattern was well replicated not only at 36MPa, but also at 22MPa. However, a nano lens array was not so well reproduced on replicated PMMA film at 22MPa. In particular, the edge portion of replicated film was scarcely filled with polymer. In this case, relatively high pressure is required for good transcriptability of MNCS film.

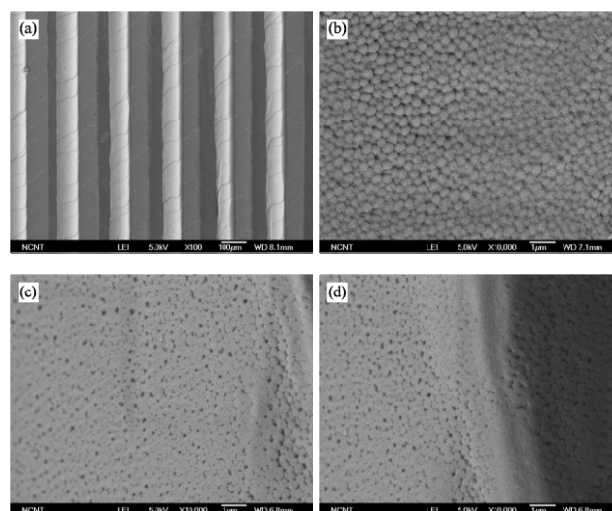


Figure 5. SEM images of the replicated PMMA film (22MPa): (a) film's several portions, (b) flat portion, (c) inclined portion, and (d) edge portion.

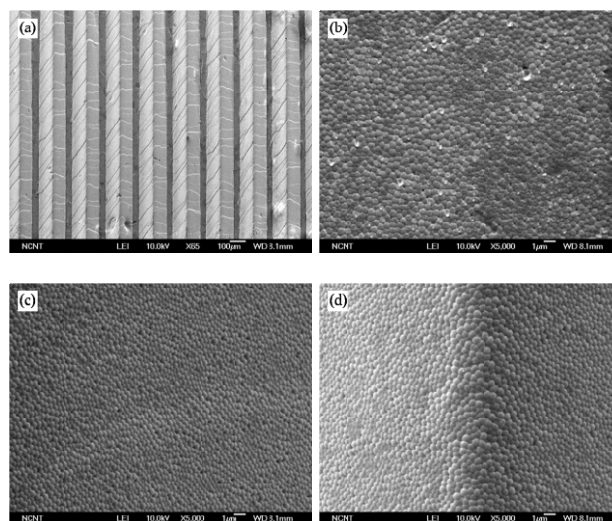


Figure 6. SEM images of the replicated PMMA film (36.6MPa): (a) film's several portions, (b) flat portion, (c) inclined portion, and (d) edge portion.

4.2 Contact angle characteristic

We have measured contact angles of replicated COC films, a flat surface and film with microstructure only as mentioned above. It may be mentioned that the contact angle of a flat COC film is 91.5°. Figure 7 summarizes the measured contact angles for comparison between MNCS film and only micro structured film. Contact angle on MNCS COC film is higher than that on only micro V-grooves film by 5° in the transverse direction and by about 10° in the longitudinal direction. It has been confirmed that nano structure added on top of microstructure certainly increases the hydrophobicity.











Flat surface	M structured COC	M structured COC	M/N structured COC	M/N structured COC
				
				
$\theta = 91.5^\circ$	$\theta = 89.3^\circ$	$\theta = 132.3 \pm 1.5^\circ$	$\theta = 94.5 \pm 1.2^\circ$	$\theta = 144.1 \pm 2.5^\circ$

Figure 7. Photos of a water drop on COC films and comparison of contact angle between MNCS film and only micro V-grooves film.

5 CONCLUSION

In this paper, we present an easy and efficient fabrication method of plastic replicas of MNCS. The MNCS films of PMMA and COC have been successfully replicated using an aluminum stamp with micro/nano combined structure (ASMNCS) via hot embossing. Relatively high pressure was required for good transcriptability of MNCS in the hot embossing process. And MNCS have a favorable effect on the hydrophobicity of COC film.

ACKNOWLEDGEMENTS

The authors would like to thank Defense Acquisition Program Administration and Agency for Defense Development (UD060049AD) and the Korea Science and Engineering Foundation(KOSEF) grant funded by the Korea government(MOST) (R01-2005-000-10917-0)

REFERENCES

- [1] Metin Sitti, "Synthetic Gecko Foot-Hair Micro/Nano-Structures as Dry Adhesives", Appeared in Journal of Adhesion Science and Technology, VOL.18, pp.1055-1074, 2003
- [2] Dong Sung Kim, Han Ul Lee, Nam Hyo Kim, Kun-Hong Lee, Dong-Woo Cho and Tai Hun Kwon, "Fabrication of microchannel with nanopillar array using micromachined AAO", Micro- and Nano-Engineering, In: Proceedings of 32nd international conference on micro- and nano-engineering: P-NSC45
- [3] Jang Min Park, Nam Hyo Kim, Bong-Kee Lee, Kun-Hong Lee, Tai Hun Kwon, "Nickel stamp fabrication and hot embossing for mass-production of micro/nano combined structures using anodic aluminum oxide", Microsystem Technology, online first, 2008
- [4] D. Mijatovic, J. C. T. Eijkel and A. van den Berg, "Technologies for nanofluidic systems: top-down vs. bottom-up—a review", Lab Chip, 5, 492-500, 2005

- [5] Ralf B. Wehrpohn, "Ordered Porous Nanostructures and Applications: chapter3.Highly Ordered Nanohole Arrays in Anodic Porous Alumina", ISBN: 0-387-23541-8
- [6] Chang Liu, "Foundations of MEMS: Chapter 10. Bulk Micromachining and Silicon Anisotropic Etching", ISBN: 0-13-147286-0