Replication of nano dimple structures by injection molding with rapid thermal control system

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ABSTRACT

Recently, nano structures are attracting more and more attention in various research fields of biomimetics, photonic crystals and so on. Such nano structures are commonly fabricated by using high-cost and low throughput procedures like e-beam lithography and nano imprinting lithography. Mass production methods, for example injection molding, are rarely utilized for nano structure replications due to a difficulty of making strong mold inserts. In this regard, the present study investigates the feasibility of a replication of nano dimple structures by injection molding. The present study proposes an efficient and easy mass production method for nano dimple structures by injection molding. Anodic aluminum oxide (AAO) technique is utilized to make a master with nano dimple structures, and then nickel mold insert is realized by using nickel electroforming (NE) technique with the AAO master. For a successful replication via injection molding, temperature is to be controlled with the help of namely rapid thermal control (RTC) system.

Keywords: nano structure, anodic aluminum oxide, nickel electroforming, injection molding, rapid thermal control system

1 INTRODUCTION

Due to the excellent replicable property and mass productivity, injection molding technique has been used in various research fields and industries. With development of micro chip [1], digital appliances and so forth, micro and nano scale replication techniques are attracting more attention in various research fields and industries. Their current and projected applications include mass storage equipments (Compact Disc, Digital Versatile Disc, Blue-Ray Disc, etc.), optical devices (LCD back-light unit, photonic crystals, etc.), biomimetic substrates (Gecko's foot, Self-cleaning surface [2], etc.), and biochemistry (cell culturing [3], tissue engineering, etc.).

Existing popular storage equipment, DVD, has about 1μm surface structure size. On the other hand, the next generation of high density storage equipment, Blue-Ray Disc, has below 400nm surface structure size. Interest on small and mass storage equipment is increasing more and more. For display appliances like LCD monitor, surface structure size and shape of back-light unit determine the video quality. Research for display appliances also focus on

large scale display by making large area of surface structure. In biomimetics, some organs of animals and plants have been found to have special functions with nano scale structures. On the foot skin of Gecko, crawling about on wall and ceiling, high aspect ratio nano pillars are observed. And on the surface of Lotus leaf which has self-cleaning effect, there are combined structure of micro particles and nano wax crystal. Several research fields focus on reproducing these special features. More uses of such nano structured templates could be found in cell culturing and tissue engineering for the purpose of separation, in-grouping, growing and so on. In many cases, nano structures are fabricated by means of e-beam lithography and nano imprinting lithography. Such processes, however, have high-cost and low throughput and limitation for large area application. On the other hand, Anodic aluminum oxide (AAO) process is quite economic since it needs just cheep materials, chemicals and devices. From AAO technique, somewhat arranged nano dimple or pore structures with 50~500nm pore-to-pore distance can be realized [4]. Also, shape and size of structures can be controlled by electrolyte type and electric current. Such AAO technique was used in recent researches like photonic crystal [5], nannochannel-array [6], bone implant [7], and so forth.

Mass production methods, for example injection molding, are rarely utilized for nano structure replications due to a difficulty in making strong mold insert. Nano structures fabricated by most lithography techniques and AAO process are composed of weak materials, like polymer, ceramic or aluminum, for using mold insert. In order to overcome this limitation, our research group has employed nickel electroforming technique [1]. Injection molding is the most typical mass production method. As a replication cycle time is shorter than any other replication processes like lithography and embossing, it have been used in various industries. Recently, injection molding for micro scale structures are achieved in plenty. Nano scale injection molding, however, still remains within a laboratory level [8].

The present study aims at a replication of nano structures by injection molding. Nickel mold insert is realized by using anodic aluminum oxide (AAO) and nickel electroforming techniques. In particular, mold insert temperature is controlled intensively during the injection molding process with the help of namely rapid thermal control (RTC) system [9].

2 EXPERIMENTAL

The overall replication procedure consists of three steps: i) basic nano structure template fabrication by means of AAO technique, ii) mold insert fabrication via nickel electroforming and iii) injection molding with the help of rapid thermal control system.

2.1 Fabrication of basic nano structure

To fabricate nano dimple structure, anodic aluminum oxide (AAO) technique was used. On the surface of 15mm x 15mm (width x length) pure aluminum template (99.999%, Good fellow), fabrication was realized step by step as described below. Figure 1 shows AAO fabrication process.

First, surface of template was electro-polished in 7℃ solution of perchloric acid and ethyl alcohol with 1:4 volume ratio. In this reaction, thin oxide layer was formed and melt in the solution. Therefore, surface of template became very smooth. Second, anodic oxidation was progressed in 0℃, 0.1M phosphoric acid as a electrolyte with 195 voltage for 16 hours. As shown in figure 1, disorganized alumina layer was formed from this reaction. Third, to remove the alumina layer, etching process was progressed in 65℃ solution of 9g chromium oxide, 20.2ml phosphoric acid and 500ml de-ionized water for 5 hours.

As shown in Figure 1(b), AAO template with nano dimple structure was fabricated. Nano patterns are well ordered and their pore to pore distance is about 500nm.

2.2 Fabrication of mold insert

To fabricate strong mold insert which withstands high pressure and rapid thermal change, nickel electroforming process was carried out on the nano structure template as a master. The whole nickel electroforming is shown in Figure 2(a) including a mold base and Figure 2(b) shows nickel electroformed mold insert and its surface SEM image.

2.3 Injection molding

In order to achieve a good trascriptability of nano structure in the injection molding process, one needs to set up and control temperature history during one cycle. In general molding case with micro scale or larger scale, melt and mold temperatures are fixed in adequate value which is usually given by polymer manufacturer. However, such a common processing condition (summarized in Table 1) turns out to be inadequate for replicating nano scale structures, mainly due to a fast solidification of molten polymer near the mold surface region. To resolve this issue, RTC (rapid thermal control) system is introduced particularly in the present injection molding process. RTC system increases locally and temporally the temperature of mold insert up to glass transition temperature of polymer, and consequently provides a more effective condition for the replication of

nano structures with a better transcription quality. Figure 3 shows schematic view of the mold with RTC heater.

Melt temperature	285°C
Mold temperature	90°C
Filling time	0.20~0.40 sec
Packing time	2.0 sec
Packing pressure	140 ~ 160 MPa
Cooling time	15~25 sec

Table 1: Conventional injection molding processing condition with LUPOY
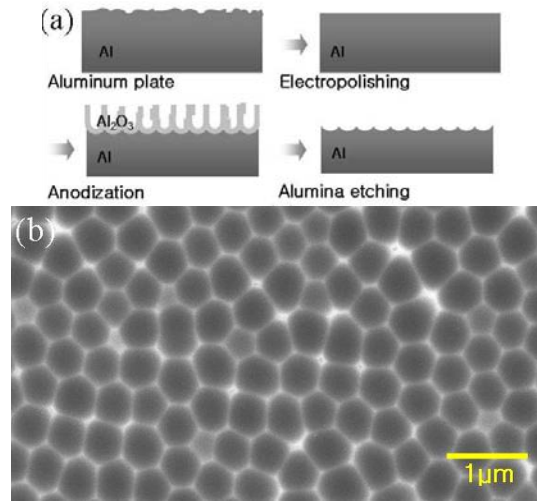

Figure 1: (a) Schematic diagram of AAO process. (b) SEM image of surface nano dimple structure of AAO template.
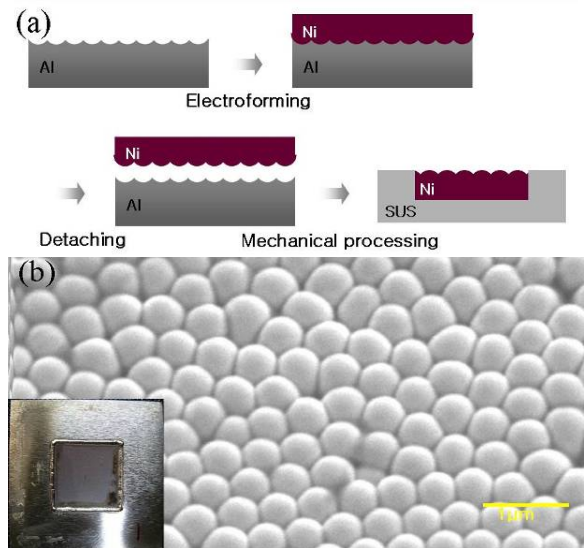

Figure 2: (a) Schematic diagram of nickel electroforming. (b) Image of mold insert and SEM image of surface nano lens-shape structure of mold insert.
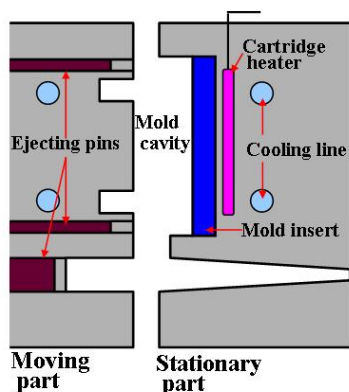
Figure 3: Schematic view of the mold with RTC heater [9]. Before injection of polymer melt, the heater increases the surface of mold insert. The temperature of the mold insert is measured by the thermocouple and monitored by the outside control box (not showed in the figure).
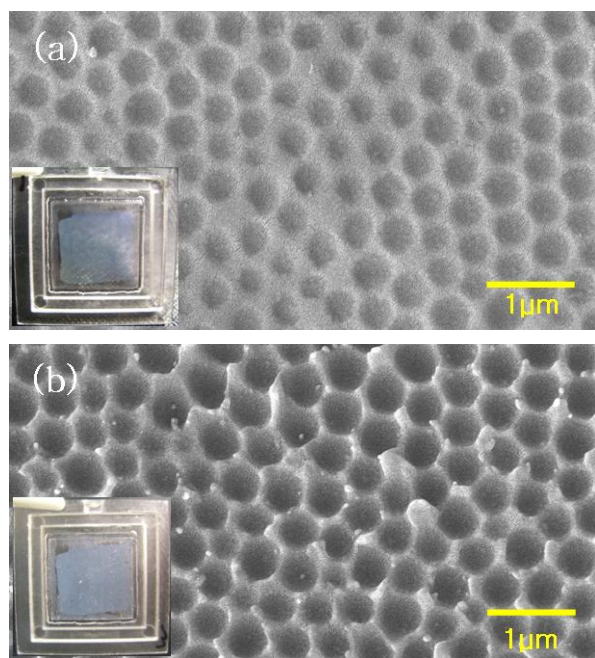

Figure 4: Image of replica which was made by (a) conventional case and (b) RTC system applied case, and their SEM image.

In the present study, injection molding experiment is carried out with RTC system and without RTC system (i.e. a conventional case) to find the effect of RTC on the transcription quality. As for the injection molding polymer, LUPOY (GP1000M, LG chem.) was used.

Figure 4(a) shows the image of replica which was made by the conventional case and its SEM image, and Figure 4(b) shows the images of RTC system applied case. As a means of measuring the transcriptability, we measured the dimension of structures in the molded article from both the conventional case and RTC system applied case: wall thickness of dimple of the latter is thinner than the former and depth of dimple of the latter is deeper than the former. From this result, RTC system provides a more effective condition for the replication of nano scale structures with better transcription quality.

For the detailed comparison, surface structures of basic AAO dimple template, nickel mold insert and replicas of injection molding were observed by AFM (Dimension3100 with Nanoscope Ⅴ in NCNT, POSTECH). Figure 5 shows the analysis result of basic AAO dimple template. The average height of nano dimple is about 120~140nm. Figure 6 shows the analysis result of nickel mold insert. Lens-shape structures are well arranged. Height of structure is about 120nm, close to the dimple depth. Figure 7 shows the analysis result of replica via injection molding with conventional condition. Dimple wall is a little bit blunt and Depth of dimple is about 100nm. Figure 8 shows the corresponding result from the replica of injection molding with RTC system. Dimple wall is sharp and some abnormal peaks are observed. These peaks might be formed by stretching during the demolding process. Depth of dimple is almost 120nm, close to the height of lens in the mold insert. As expected, from the result of AFM analysis, RTC system provides a more effective condition for the replication of nano scale structures with better transcription quality.

3 CONCLUSION

From the results of SEM images and AFM analysis, it is confirmed that the introduction of RTC system improves drastically the transcription quality of nano scale injection molding. As nano dimple structures are relatively simpler than any other structures, it was easy to be replicated by injection molding. For the cases of more complex structures, for example high aspect ratio structures, there may be problems in demolding process.

As interest in nano structures increases in various research fields of biomimetics, photonic crystals, cell culturing and so forth, this successful replication of nano structures via injection molding would open up windows widely to various applications of this technology towards interdisciplinary research fields of IT and BT.
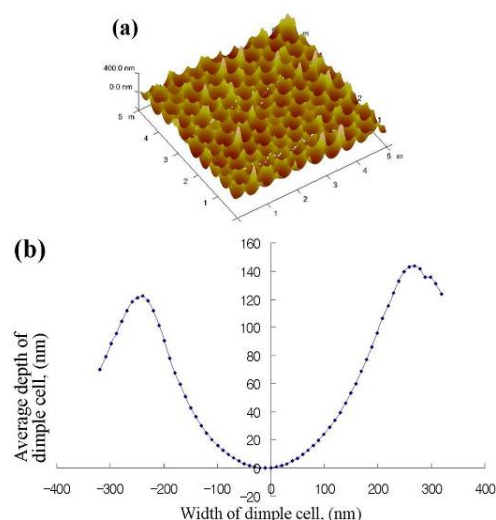
4 ACKNOWLEDGMENT

Figure 5: AFM analysis results of AAO dimple template; (a) 3D image, (b) average cross section data graph.
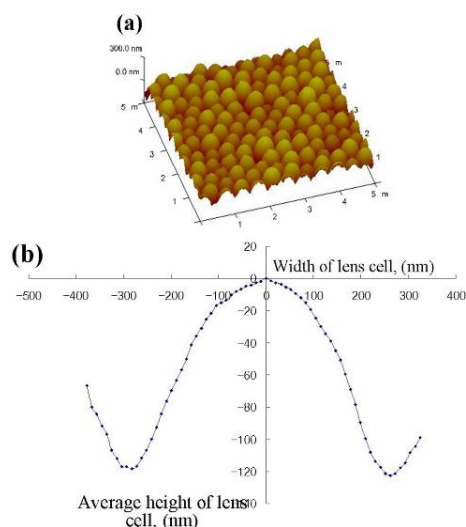

Figure 6: AFM analysis results of nickel mold insert; (a) 3D image, (b) average cross section data graph.
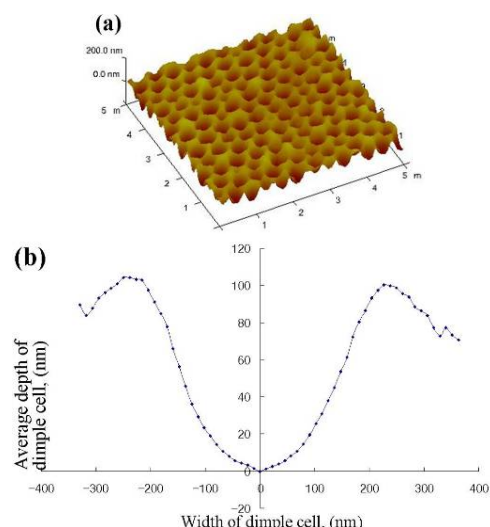

Figure 7: AFM analysis results of replica of injection molding without RTC; (a) 3D image, (b) average cross section data graph.
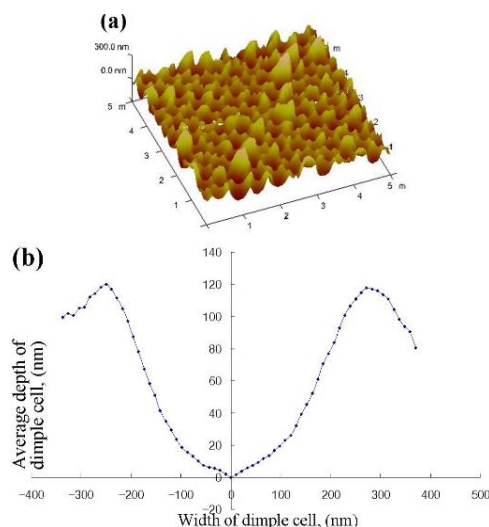

Figure 8: AFM analysis results of replica of injection molding with RTC system; (a) 3D image, (b) average cross section data graph.

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