Large-scale mold preparation for R2R systems by a novel mold replication and global shrinking process

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ABSTRACT

The demand for applying the functional surface having micro/nano structures is gradually increasing in our lives and industrial field however. However, one of the critical limitations of replicating structured functional surface is the low productivity. To address this problem, we report a new fabrication strategy of making large-area mold from an original mold with larger feature sizes, and applied it in a roll to roll (R2R) nanoimprint system. Through this study, we can achieve large-area nanograting sample without resorting to complex and costly fabrication processes. This fabrication strategy could be utilized in various fields.

Keywords: nanostructure, shrinkage, large-scale mold, R2R system

1. INTRODUCTION

Functional surfaces based on micro/nano structures have found many applications with remarkable properties being demonstrated using imprinting or molding fabrication processes.[1] However, one of the critical limitations of the functional surface is its low productivity such as only small-area sample can be made, to a large extent due to the high cost of large area master mold fabrication. To overcome these problems, much research has been dedicated to developing new fabrication methods of large-area mold and roll-based continuous fabrication of the micro/nano structures, and realizing various types of roll to roll (R2R) systems.[1-4] Despite these admirable efforts, fabrication of large-scale master mold having nanostructures still remains a demanding task, not easily accessible to many researchers. One of the commonly used methods for the micro/nano master mold fabrication is to use photolithography for patterning. The photolithography is well-established and can be used for the fabrication of the large-scale mold. However, the minimum feature size by photolithography is restricted by the light diffraction limit.

In this study, we propose a new fabrication strategy of the large-scale nanostructured mold from the sub-micron structured mold fabricated by the photolithography. The large scale nanograting was achieved by exploiting the shrinkage of an imprint-replicated sample. Furthermore, we apply the made sample with reduced feature-size to a custom-built R2R equipment and carry out the continuous fabrication. Through this study, we believe this fabrication strategy could be utilized in various applications.

2. EXPERIMENTAL AND RESULTS

Polymer shrinkage after cross-linking is well known and the shrinkage rate depends on the type of polymers. In this work, by using highly shrinkable water-based polymer, large-scale nanostructured mold can be fabricated easily from the master mold with sub-micron features. In this case, a master grating mold is fabricated by conventional photolithography with a grating period of 1.6 μm and linewidth of 835 nm and the fabrication method is illustrated in Figure 1.

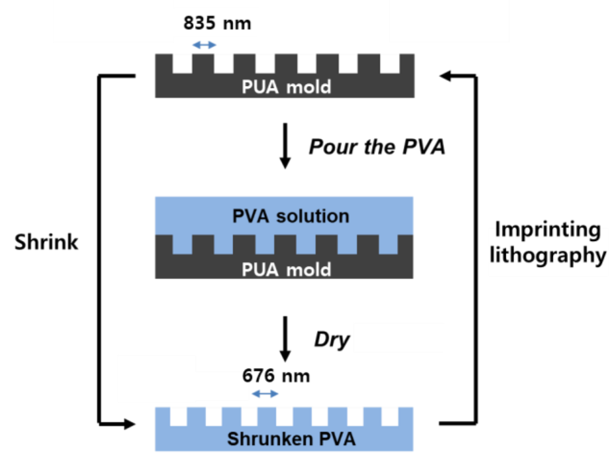

Figure 1. Illustration for the fabrication strategy

As shown in Figure 2, a first replica with a linewidth of 765 nm from the master mold was prepared by using nanoimprint lithography (NIL); next the shrinkable polymer was replicated from the first replica, and subsequent crosslinking resulted in significant shrinkage of the entire sample. Then, the third replication from the shrunken imprint mold produces 676 nm linewidth Through this fabrication cycle, a ~ 11.6 % size and period reduction was achieved compared with the original dimension. Such a process can repeat for further feature reduction.

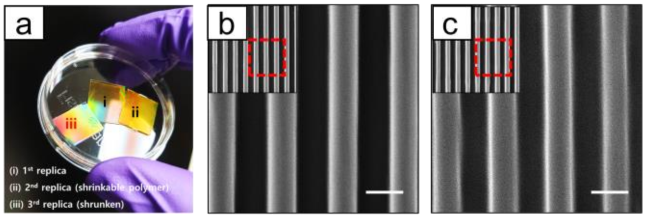

Figure 2. (a) Photograph of the fabrication result: replication from an original mold with 765 nm grating (i) 1st replica with an UV curable material (ii) 2nd replication using the shrinkable polymer from the 1st replica (iii) 3rd replica from the 2nd replication after shrunken. SEM images of (b) the 1st replica with 765 nm of linewidth. (c) the 3rd replica with 676 nm of linewidth. Scale bar is 1μm.

Through this fabrication strategy, the large-scale mold with small feature size can be achieved without resorting to advanced fabrication techniques. To demonstrate the utility of this methodology, the replicated sample was used as flexible mold in a custom-built R2R equipment, which is capable of soft baking, nanoimprint and UV curing continuously. Continuous fabrication of the nanograting was carried out. Furthermore, since the large mold was made of a UV curable polymer that is widely used for the R2R process, the continuous fabrication was implemented reliably and stably.

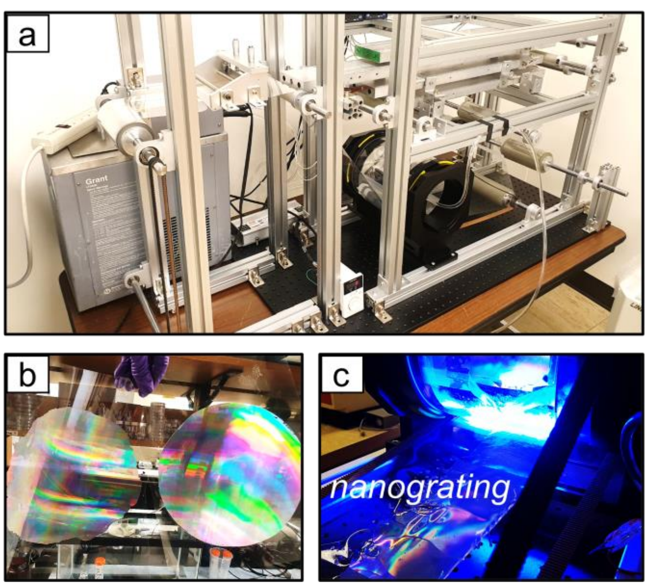

Figure 3. Photographs of (a) the custom-built R2R system (b) the large-scale nanostructured mold (c) the continuous fabrication.

3. CONCLUSION

In this study, by using the characteristic of polymer shrinkage, we developed a new fabrication strategy of making large scale nanostructured mold in a cost-effective manner. This strategy could be a useful alternative for nano-replication, and further developed into a versatile method by exploring various parameters of the material system. This fabrication strategy could be potentially utilized in diverse fields, and may go beyond 2D structures but also 3D structure fabrication.

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