Ultrasonics 54 (2014) 1495–1503

Contents lists available at ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Selective ultrasonic imprinting for micropattern replication on predefined area

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ARTICLE INFO

Article history:
Received 7 March 2014
Received in revised form 30 March 2014
Accepted 11 April 2014
Available online 19 April 2014

Keywords:
Ultrasonic imprinting
Micropattern replication
Selective patterning
Predefined area
Mask film

ABSTRACT

Conventional micro/nano patterning processes generally use rectangular patterned molds, so that the pattern replications are usually performed in a corresponding rectangular region. In this study, a selective patterning method based on ultrasonic imprinting is developed to replicate micropatterns on predefined areas with arbitrary profiles. To replicate micropatterns on predefined areas, the conventional ultrasonic imprinting process is modified by placing a profiled metal mask between a target film and an ultrasonic horn. Ultrasonic waves are then selectively transferred to the target film through the mask film, from which micropatterns can be replicated onto the predefined areas. For the implementation of the proposed selective imprinting process, the effects of the mask size and shape are experimentally investigated in terms of the replication characteristics of micropatterns. This selective imprinting process is further applied to micropattern replications on arbitrarily profiled areas. In these applications, the effects of the mask film and imprinting conditions are also discussed in terms of the replication quality in both the masked and the unmasked regions.

1. Introduction

These days, functional biomimetic surfaces have been received increasing interest in various academic and engineering fields [1]. Recent advances in nanotechnology have driven versatile biomimetic applications by enabling the fabrication of artificial micro/nano-structures: the superhydrophobic property of lotus leaves [2], the antireflection characteristics of moth eyes [3], the water harvesting of a desert beetle [4]. To fabricate these biomimetic surfaces, micro/nano patterning technology is required by which structures at these scales are replicated onto soft substrates using hard molds. Hot embossing and micro-injection molding have been used to replicate micro/nano patterns on thermoplastic polymers surfaces [5].

Hot embossing uses preheated molds to replicate micro/nano-patterns on thermoplastic polymer, and has the advantages of simple and economical setup as well as the disadvantages of long cycle times [6]. Injection molding, the most popular polymer processing method, has recently been applied in the fabrication of micro-features [7]. Because micro-injection molding has filling difficulty due to its extremely small flow channel, auxiliary mold heating technologies have been used to improve fluidity of the polymer material [8].

Recently, several researchers have used ultrasonic vibration energy to improve the moldability in various material processing technologies: hot embossing [9,10], injection molding [11,12], and metal forming [13,14]. The use of ultrasonic waves was further developed to ultrasonic imprinting that replicates micro/nano patterns on thermoplastic polymer substrates [15–17]. Ultrasonic imprinting was also applied to the fabrication of superhydrophobic surfaces by forming micro/nano hierarchical structures on thermoplastic polymer substrates [18,19].

In NIL processes, mold inserts are essentially used to replicate micro/nano patterns on polymer substrates. The mold inserts are fabricated by various tooling methods including mechanical micro machining, laser structuring, electric discharge machining (EDM) and lithographic processes with X-rays or UV radiation combined with electroplating [20]. In these processes, micro/nano patterns are fabricated directly on the surfaces of mold inserts or on the electroplated nickel stamps which are attached to the mold surface. These patterned regions usually have a rectangular shape for the sake of easier manufacturability of the micro/nano patterns.

On the other hand, recent applications for the development of functional surfaces have required the use of patterned surfaces with arbitrary profiles or shapes. Choi et al. [21]developed a

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http://dx.doi.org/10.1016/j.ultras.2014.04.015
0041-624X/

micro/nano hierarchical structure for a superhydrophobic surface, and performed deep ultraviolet exposure through a profiled mask in order to confer hydrophilic properties on the exposed regions. Ko et al. [22] mimicked a beetle wing by combining selective etching and nanopillar fabrication. Hanske et al. [23] developed hierarchical particle assemblies by transferring nanoparticles on chemically patterned substrates. Na et al. [24] fabricated an artificial iris with self-regulating spoke patterns by UV imprinting and selective wetting inscription. Yang et al. [25] selectively exposed polydimethylsiloxane (PDMS) substrates to O_2 plasma. In these studies, an additional development process using hard masks or specially fabricated molds was required for replication of the micro/nano patterns on the profiled regions.

The present study proposes a facile fabrication method to develop micropatterns on predefined areas with arbitrary profiles. The proposed process is based on ultrasonic imprinting, and uses a profiled mask film unlike the normal imprinting process. That is, a profiled mask film is placed between the horn surface and the target film; where ultrasonic waves are transferred through the mask film. Thus, the regions in contact with the mask film are softened locally, so that micropatterns can be selectively replicated in these regions. In this study, the validity of the proposed selective imprinting process was investigated by experiments. Effects of mask design and imprinting conditions are discussed in terms of replication ratio, in both the masked and the unmasked regions.

2. Selective ultrasonic imprinting process

2.1. Process overview

The ultrasonic imprinting process uses ultrasonic vibration energy to soften the surface of thermoplastic polymer for micropattern replication. Fig. 1a shows a configuration of the conventional imprinting process. A number of micropatterns are engraved on the mold surface, and the horn vibration is transferred to the mold surface through the polymer film (target film). This ultrasonic vibration causes repetitive deformation and the resulting frictional heat on the polymer surfaces. Thus, the surface region of the target film is sufficiently softened that the micropatterns engraved on the mold can be replicated. The ultrasonic imprinting system involves the following steps: (i) a polymer film is installed in the mold, (ii) the horn vibrates due to ultrasonic excitation, (iii) the horn presses the softened polymer film and (iv) the horn recedes and the patterned film is removed from the mold.

In this study, a method for selective micropattern replication is proposed based on the ultrasonic imprinting process. Fig. 1b illustrates a schematic description of the selective imprinting process. A mask film that has an arbitrary profile is located between the horn surface and the target film. Ultrasonic wave is then transferred from the horn to the target film through the mask film. Thus, in the target film, only the regions contacted with the mask film are affected by the ultrasonic excitation. Micropatterns can then be selectively replicated in these regions where the target film is locally softened.

2.2. Micropattern replication using selective imprinting

Experiments were performed to verify the effectiveness of the proposed method. Amorphous polyethylene terephthalate (APET) films of 0.3 mm thickness (Woongin Chemical Co., Ltd.) were used as target films, of which glass transition temperature (T_g) and melting point (T_m) are 76 °C and 250 °C, respectively. Thin aluminum alloy sheets (AA-1050) of 0.4 mm thickness were used as mask films, due to its high ultrasonic transmission capability. The size

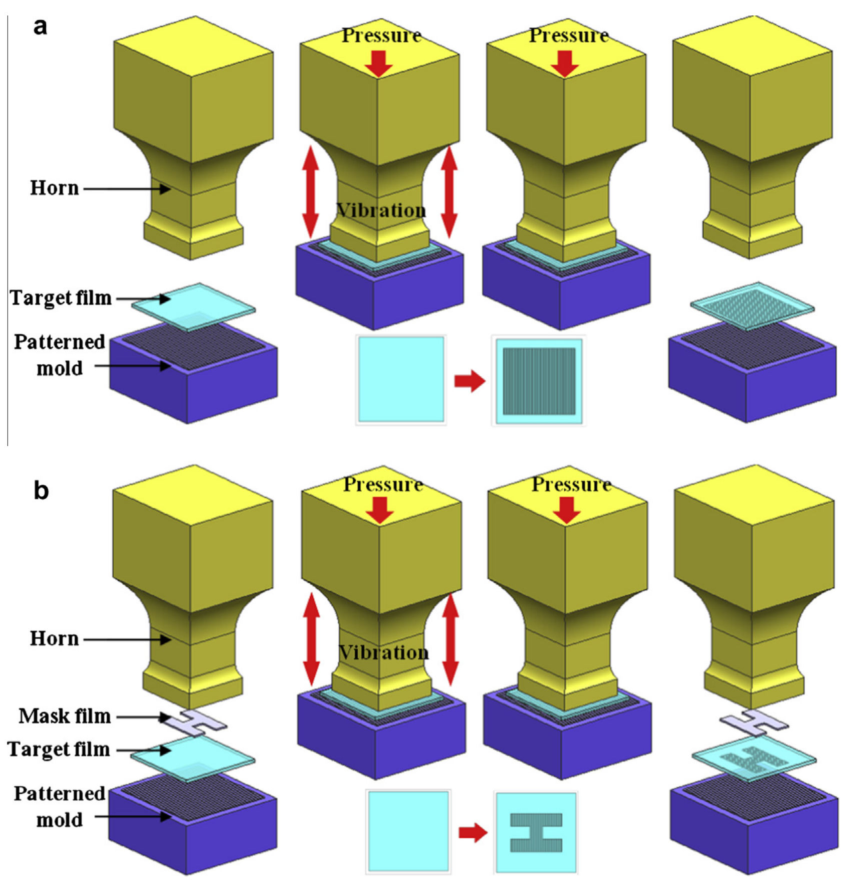

Fig. 1. Configurations of the ultrasonic imprinting process: (a) conventional imprinting, and (b) selective imprinting.