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Electromagnetic force-assisted imprint technology for fabrication of submicron-structure

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ABSTRACT

This paper reports a novel imprint technique for fabrication of polymeric submicron-scale structures. In use of electromagnetic force to press the magnetic stamp written with submicron-scale structures into a UV-curable resist on the substrate, the liquid photopolymer can be patterned at room temperature.
In this study, an electromagnetic force assisted imprinting facility with UV exposure capacity has been designed, constructed and tested. Under the proper processing conditions, the polymeric submicron-scale structure with feature size of 500 nm across a 150 mm^2 area can be successfully fabricated. Scanning electron microscopy (SEM) and atomic force (AFM) observations confirm that the submicron-scale polymer structures are produced without defects or distortion and with good pattern fidelity over a large area. This technique shows the potential for efficient fabrication of submicron-scale structures at room temperature and low pressure on large substrates with high productivity at low cost.
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1. Introduction

In recent years, the polymeric micro- and nanostructure has been widely used in various fields such as optoelectronics systems, sensing devices and biomedical engineering. Nanoimprint lithography has been introduced as an alternative technique to electron beam, ion beam, or X-ray lithography for replicating high resolution patterns with high productivity at low cost. There are several methods for nanoimprint technologies. Some examples are hot embossing lithography [1–4], step-and-flash imprint lithography with transparent quartz stamp [5–6] and soft lithography [7–10].

In hot embossing lithography, the microstructure or nanostructure patterns can be formed by heating a thermoplastic resist layer coated on the substrate above its glass transition temperature, pressing the resist layer with a rigid mold, and subsequently cooling the polymer to below its glass transition temperature. The process involves temperature cycling and high pressure processing. It is very time-consuming and needs expensive facilities. As an alternative, the step-and-flash imprint lithography was developed. It uses UV-curable resist and employs UV light to cure the photopolymer at low pressure and room temperature. However, this procedure requires transparent quartz stamps that apply a complex fabrication process and can be more expensive than the usual rigid stamps. On the other hand, the soft lithography processes utilize soft PDMS stamp and low viscosity resists, allowing short process cycle and accurate structure transfer. However, the conventional soft lithography and imprinting processes is limited by mechanical nature in a mechanical press in which the pressing force comes from a central column and pushes a plate. The deflection and non-parallel contact of pressing plates will cause the non-uniformity of imprint pressure between PDMS stamp and substrate. The low rigidity of PDMS will often cause the microstructures on the PDMS stamp to deform or to distort generating defects in the pattern.

In this study, the authors present an innovative method, electromagnetic force-assisted UV-imprint technology, which employs the electromagnetic force to pull the magnetic stamp with submicron-scale structures into a UV-curable resist on the substrate. The liquid photopolymer is then cured by UV-irradiation at room temperature and does not involve temperature cycling or high pressing action during processing. By using this method one can reduce the problems of conventional imprinting method to improve the performance of nanoimprint technology.

In this technique, the magnetic stamp is made by casting a prepolymer of PDMS between a silicon master and a rigid flat nickel support piece. After PDMS curing, the silicon master is separated from the PDMS/nickel piece. The thin layer of PDMS remains adhered to the nickel support, and the magnetic stamp is obtained.

In the experiment, an electromagnetic force-assisted imprinting facility with UV exposure capacity has been designed, implemented and tested. The surface profile of imprinted submicron-scale structures is measured using atomic force microscope (DI-3100, Veeco Inc.) and inspected by scanning electron microscopy

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(JSM-5600, JEOL, Japan). The uniformity of imprinted patterns are measured and analyzed.

2. Experimental setup

2.1. Fabrication of magnetic mold with submicron-scale structures

Fig. 1 describes the schematics of magnetic mold fabrication. First, a 150 mm^2 silicon wafer with submicron-scale structures is fabricated by e-beam lithography and reactive ion etching. Next, a pre-polymer of PDMS is poured between a silicon wafer and a rigid flat nickel piece. After curing of the pre-polymer, the PDMS mold with nickel support can be peeled off from the silicon wafer. The magnetic mold with submicron-scale structures can be obtained. Fig. 2 shows the cross-section of structure on PDMS mold. The pattern on the PDMS mold has a line width of 502–504 nm, a pitch of 1 μm and a depth of 200–203 nm.

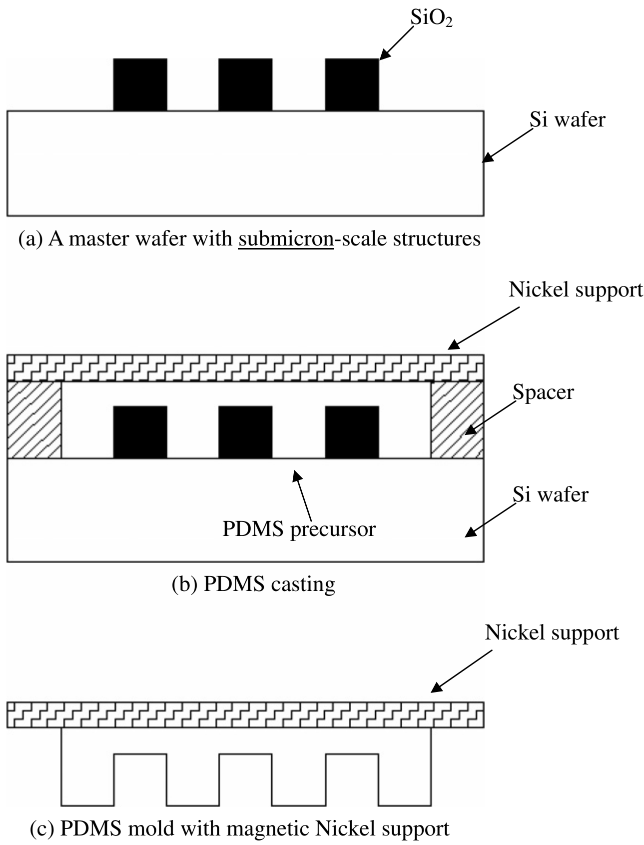

Fig. 1. Schematic diagram illustrating fabrication of magnetic mold.

2.2. Electromagnetic force-assisted imprint apparatus and process

Fig. 3 shows the electromagnetic force-assisted imprinting facility with UV exposure capacity used in the current experiment. The system consists of a UV-transparent top plate (glass plate), an imprinted substrate, an UV-lamp, and an electromagnet with power supply.

The current of electromagnet is controlled by the power supply, thus the imprinted forced is controlled. The wavelength of the UV-lamp is between 365–410 nm. The UV intensity at 365 nm is 100 $mJ/cm^{2.}$ The UV-curing dose is equal to the intensity of UV-light times the curing time. A UV curable resin mr-L6000 (Microresist Technology GmbH, Germany) is used. Note that the imprinted substrate is a glass substrate or transparent plastic film. This novel process is thereby capable for specific applications such as optical device and transparent component.

The electromagnetic force-assisted UV-imprint process can be divided into four stages as illustrated in Fig. 4.

(1) Preload stage: The stack of magnetic mold with submicron-scale structures and the plastic substrate coated with UV-curable resist is placed on the top plate of facility. Consequently, the weight of magnetic mold is applied to the resist layer as preload on the substrate.
(2) Pressing stage: The voltage is applied between the mold and the substrate, the magnetic mold with submicron-scale structures is pressed against the UV-curable resist layer on the plastic substrate with proper molding pressure for a certain period of time (t1–t2). The liquid resist fills into the mold cavities.
(3) Curing and packing stage: After the pressing time period (t1–t2), the UV curable resist is cured by UV-irradiation at room temperature, while maintaining the pressure (P) to prevent uncontrolled shrinkage and distortion.

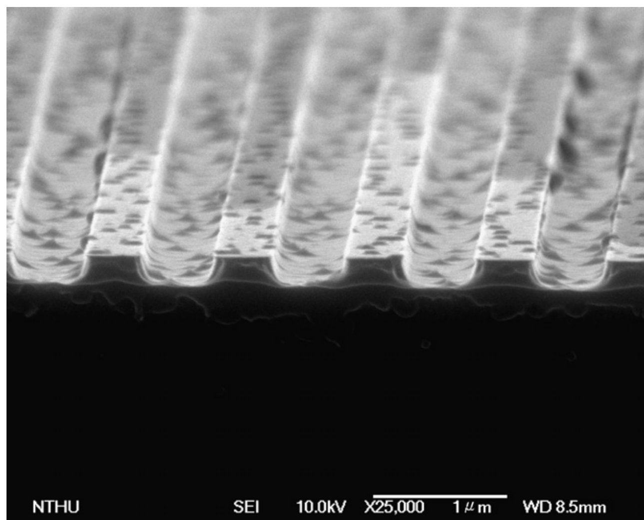

Fig. 2. SEM image of cross section of PDMS mold.

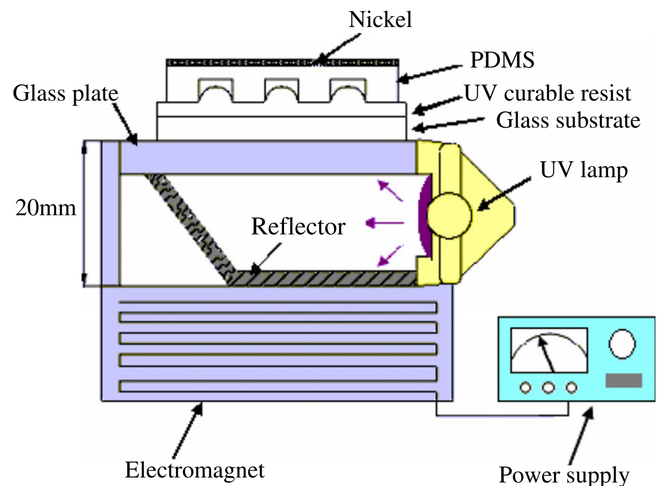

Fig. 3. Schematic diagram of electromagnetic force assisted imprinting equipment.

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