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Super-resolution technique for nanoimprint mold using elastic UV-curable resin

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ABSTRACT

There is a strong need for a nanoscale patterning method that offers high throughput and is cost-effective. Nanoimprint lithography (NIL) is a major breakthrough for next-generation lithography (NGL) due to its high resolution and simpler process compared to conventional nanoscale patterning techniques. However, as the resolution of NIL depends on the mold size, it is very important to fabricate a fine mold. High-resolution electron beam lithography (EBL) is typically used for mold fabrication, but a large-area mold is difficult to fabricate because of the low throughput of EBL. Moreover, electron scattering, which causes the proximity effect, is a troublesome issue in the EBL process. The proximity effect enlarges the size of the pattern that forms after development of the resist compared to the design pattern size, and makes it difficult to produce a mold pattern that is fine and dense. Therefore, a high-throughput fine patterning technique for a large-area mold is strongly desired. In this study, we demonstrate a super-resolution technique for an NIL mold with a line-and-space (LS) pattern using elastic ultraviolet (UV)-curable resin. As a result, we have succeeded in fabricating a reduced-size replica mold, which is almost half again the density of the master mold, and confirmed UV nanoimprint replication with the reduced-size mold.

1. Introduction

There is a growing demand for a nanoscale patterning technique for fabricating next-generation devices. Especially, a fine line-and-space (LS) pattern is required in various fields, such as printed electronics (PE), plasmon photonics and optical devices. For example, transparent conductive sheets [1], plasmon color filters [2], and wire-grid polarizers [3] need a fine metal LS pattern over a large area. For producing this type of pattern, nanoimprint lithography (NIL) [4] and nanotransfer printing (NTP) [5] have received considerable attention as techniques that simultaneously deliver high throughput and high resolution. However, the resolution of NIL and NTP depends on the mold feature size, since these techniques are based on a direct contact process. Therefore, it is very important to fabricate a fine-patterned, large nanoscale mold. High-resolution electron beam lithography (EBL), which is carried out under high vacuum conditions, is typically used for the mold fabrication [6–10]. However, EBL has some troublesome issues. For instance, a large-area mold is difficult to fabricate because the EBL process is low-throughput and the work size is restricted by the vacuum chamber size. Moreover, electron scattering in the electron beam resist unavoidably causes such issues as the proximity effect [11], which enlarges the size of the pattern that forms after development of the resist compared to the design pattern size. In order to avoid the proximity effect and fabricate a fine and dense LS mold, several techniques have been developed, for instance, the use of spin-on glass (SOG) with the post exposure bake (PEB) process [12] or the cold-development technique [13].

On the other hand, to more easily obtain a finer pattern, the deformation method using heat-shrinkable film [14] or poly(dimethylsiloxane) (PDMS) [15] has also been reported. The deformation method is a powerful yet simple process with the advantage of no need for expensive special equipment. However, the shrinkage ratio of heat-shrinkable film is mainly dependent on the material composition. Hence, when a different shrinkage ratio is required, the material composition must be modified. In contrast, it is possible to control the shrinkage ratio by using the mechanical deformation method with an elastic material, such as PDMS. However, PDMS is a high-viscosity thermosetting material, so it is difficult to quickly produce many PDMS stamps by using injection molding or roll-to-roll NIL [16]. Furthermore, it is very difficult to anchor the stretched PDMS stamp to a substrate without distorting the nanoscale pattern prior to carrying out the next step of the process.

In this study, we developed a new mechanical deformation technique, which uses the combination of elastic UV-curable resin and plastic substrate. In addition, we examined the mechanical deformation characteristics using an LS pattern master mold using our technique. Here, a replica pattern was fabricated by UV-NIL with the elastic UV-curable resin onto a polyethylene terephthalate (PET) substrate. Then, the PET substrate was heated to its glass transition temperature (Tg) and was deformed along with the elastic resin pattern. Since the deformed elastic pattern was fixed

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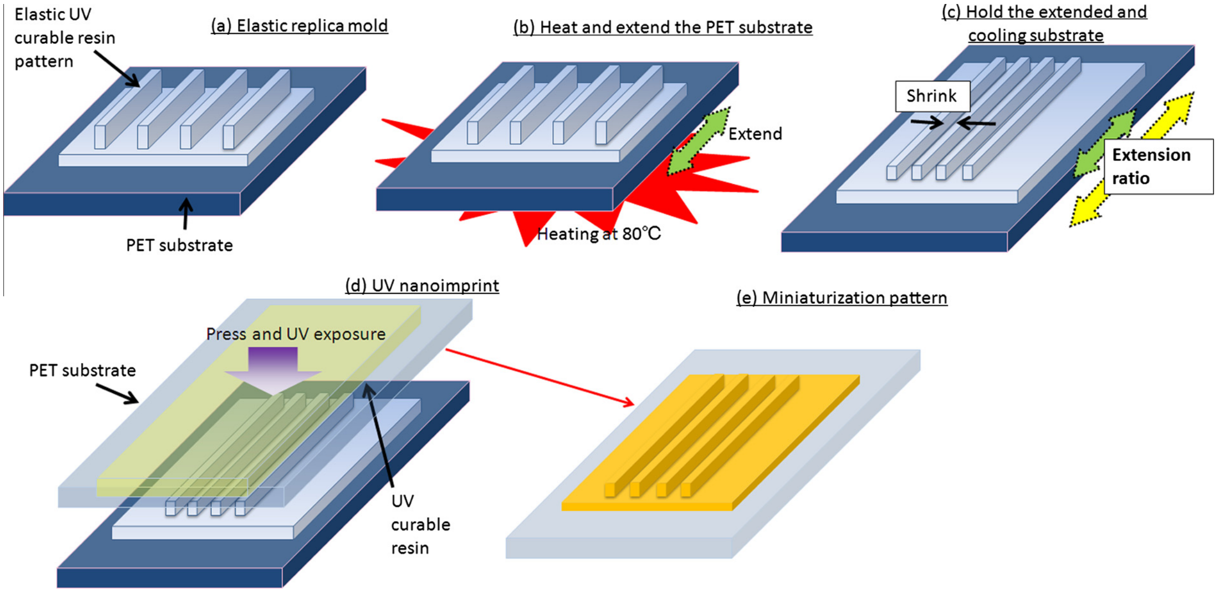

Fig. 1. Schematic diagram of the super-resolution technique in this study.

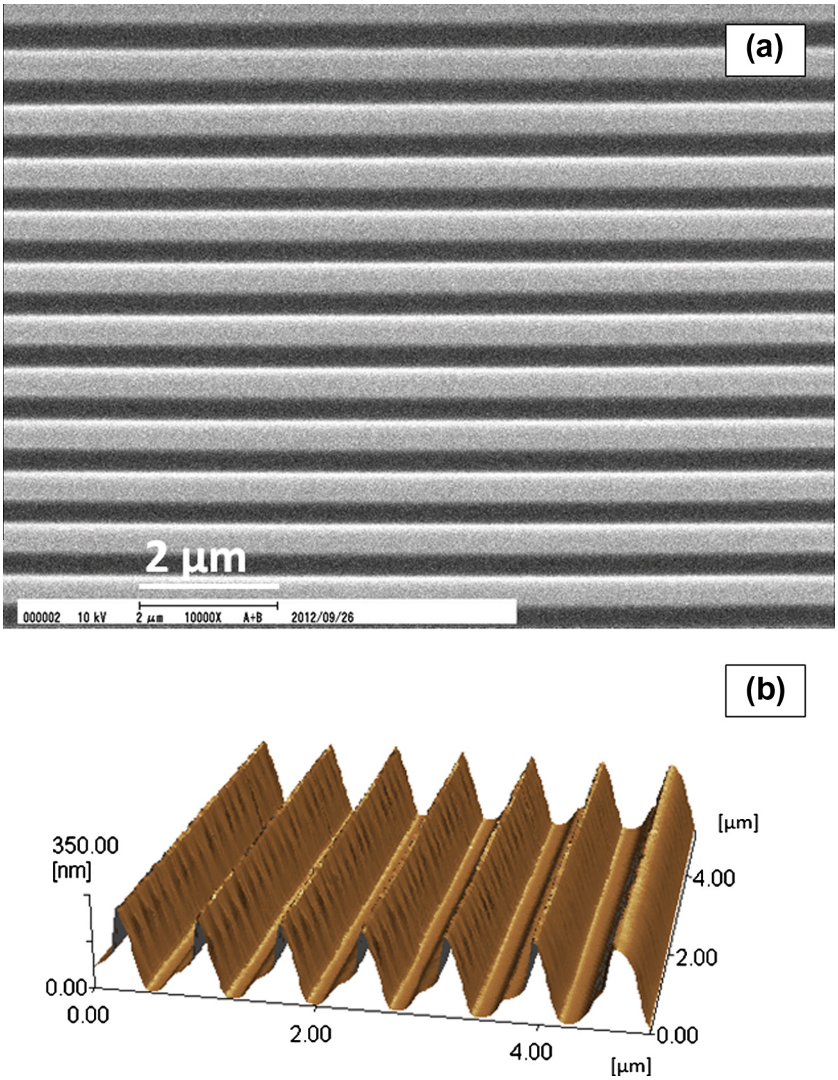

Fig. 2. (a) SEM and (b) AFM images of the initial replica mold using AUP-800.