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RESEARCH ARTICLE

Combined Laser Interference and Photolithography Patterning of a Hybrid Mask Mold for Nanoimprint Lithography

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A lithography technique that combines laser interference lithography (LIL) and photolithography, which can be a valuable technique for the low cost production of microscale and nanoscale hybrid mask molds, is proposed. LIL is a maskless process which allows the production of periodic nanoscale structures quickly, uniformly, and over large areas. A 257 nm wavelength Ar-Ion laser is utilized for the LIL process incorporating a Lloyd's mirror one beam inteferometer. By combining LIL with photolithography, the non-selective patterning limitation of LIL are explored and the design and development of a hybrid mask mold for nanoimprint lithography process, with uniform two-dimensional nanoscale patterns are presented. Polydimethylsiloxane is applied on the mold to fabricate a replica of the stamp. Through nanoimprint lithography using the manufactured replica, successful transfer of the patterns is achieved, and selective nanoscale patterning is confirmed with pattern sizes of around 180 nm and pattern aspect ratio of around 1.44:1.

Keywords: Laser Interference Lithography (LIL), Photolithography, Hybrid Mask Mold, Nanoimprint Lithography.

1. INTRODUCTION

Nanoscale periodic structures have attracted much interest of late because of their potential applications in different fields, such as in photonic crystals,[1] magnetic arrays,[2] and biomaterials.[3] The main limitation for the industrial exploitation of devices with sub-micro dimensions, however, is the absence of a cost-effective fabrication technology. Nanoscale devices are now routinely designed by means of electron beam lithography (EBL) or focused ion beam (FIB) lithography, but these methods are used only in research and prototypical applications because device production using such methods is sequential and time consuming.[4]

Nanoimprint lithography is a next generation lithography technique for the high throughput patterning of nanostructures at great precision and at a low cost.[5–7] Nanoimprinting has been applied to the fabrication of critical patterns in electronic and photonic devices. It involves a nanoscale patterning technique where a surface relief pattern on a mold is physically imprinted into an imprinting resist, cast on a substrate, at a controlled temperature and pressure.[8] However, limitations associated with the nanoimprinting technique include high cost in fabricating the master stamps.

Laser interference lithography (LIL) allows the production of periodic nanoscale structures quickly, uniformly, and over large areas. The advantage of the LIL technique is that it is a relatively simple and fast process, and the exposure and development steps can be completed in a few minutes, making it well suited for high throughput production. It can fabricate well-ordered nanopatterns on a flat surface and can easily control the pitch length and height of the features. However, the limitations of LIL include difficulties in high reproducibility, maximum and minimum feature size restriction, and especially the non-selectivity of the patterning since it involves a maskless process.[9]

Despite the limitations of LIL, its application in the fabrication of a stamp for nanoimprint lithography could be advantageous and furthermore in order to account for the

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non-selective patterning limitation of LIL, the design and the development of a combined LIL and photolithography patterning technique are suggested, and a method of fabricating a hybrid mask mold using this technique, for nanoimprint lithography process, is presented.

2. EXPERIMENTAL DETAILS

In this study, a 257 nm Ar-Ion UV laser source with a simple Lloyd's mirror configuration was used. The classic Lloyd mirror setup for interference grating formation is shown in Figure 1.

The scheme was previously reported,[10] where the frequency of a 515 nm wavelength laser was doubled using a beta-barium borate (BBO) crystal. On top of the quartz substrate, hexamethyldisilazane (HMDS) was spin coated to improve the adhesion characteristics between the substrate and the photoresist, after which a positive photoresist DHK-BF424 (DongJin) was spin coated in a resist spinner and baked at 110 °C for 60 sec. The applied exposure intensity varied between 15 and 18 mJ/cm^2, controlled by the optical power/energy meter (Newport, 1936-C). Two-dimensional (dot) arrays of the resist were generated through two consecutive LIL processes, with a 90° rotation of the sample in between the exposures. Each sample was post exposure baked at 110 °C for 60 sec, followed by the development process with the corresponding time conditions. The width and height features of the nanoscale patterns were determined by the reactive ion etching (RIE) process. With the Cr nanoscale patterns achieved, photolithography process was then performed, utilizing positive photoresist AZ1512. The resist array patterns were transferred to the underlying quartz substrate by inductively coupled plasma RIE process. The resist and Cr layer acted as a mask, allowing the exposed areas to be selectively etched. The remaining resist and Cr layer after the generation of nanoscale patterns on the quartz substrate were removed using the CR7SK (CYANTEK Co.) etching solution. All the steps of the hybrid mask mold fabrication are shown in Figure 2.

The fabricated hybrid mask mold was then used as a stamp for the nanoimprinting process. Negative patterns were achieved by applying polydimethylsiloxane (PDMS) on the mold, after which the replica was manufactured by nanoimprinting (BNP Science, modified PTI-1000) with the application of an ultraviolet (UV) curable resist (Ormocomp, Microresist Technology), under pressure of 2 bar and UV cure dosage of 5 mJ at room temperature. The residual layers were removed by RIE, with an optimized 95%/5% mixture of CHF_3/O_2 gases, for 1 min.

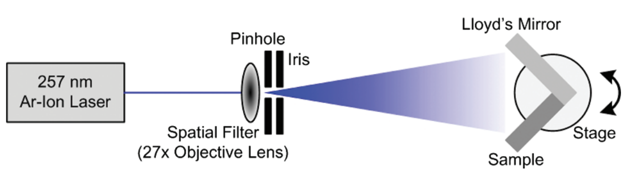

Fig. 1. Schematic diagram of the LIL process with Lloyd's mirror configuration. Reprinted with permission from [9], J. Choi et al., *J. Nanosci. Nanotechnol.* 11, 778 **(2011)**. © 2011, American Scientific Publishers.

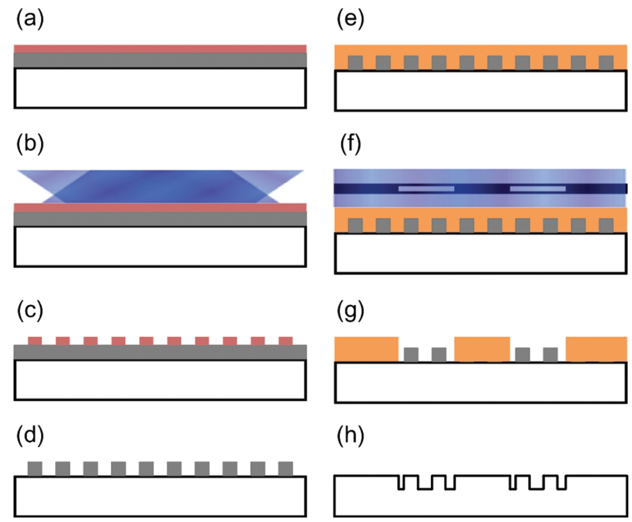

Fig. 2. Schematic diagrams of the fabrication process of the hybrid mask mold: (a) deposition of the Cr and LIL photoresist; (b) LIL exposure; (c) LIL patterning; (d) RIE of Cr; (e) deposition of the photolithography photoresist; (f) photolithography exposure; (g) photolithography patterning; and (h) RIE of quartz and removal of the residual layers.

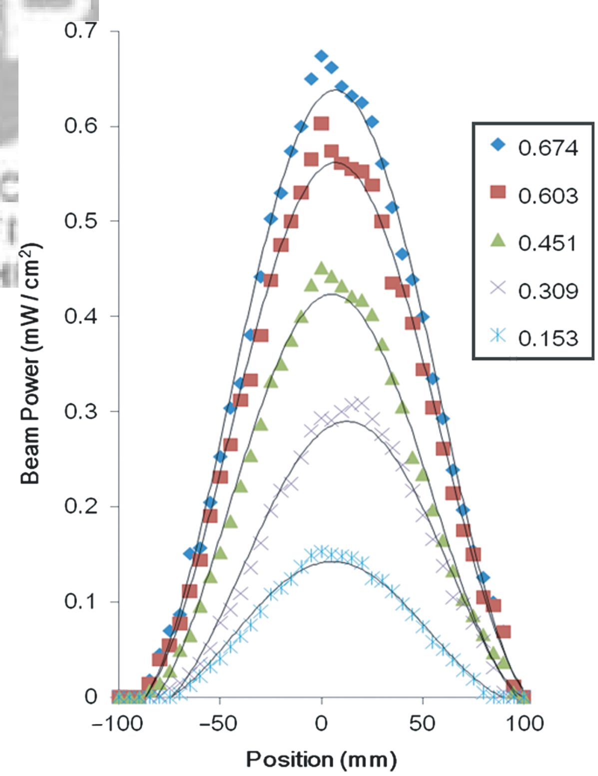

Fig. 3. Graphs of the beam power against the position of the detector. Reprinted with permission from [9], J. Choi et al., *J. Nanosci. Nanotechnol.* 11, 778 **(2011)**. © 2011, American Scientific Publishers.

3. RESULTS AND DISCUSSION

With the required energy intensity defined, for nanoscale pattern fabrication, the half angle between the two beams at the intersection was varied through the rotation of the stage. Contolling the LIL angle (θ) to be 15°, patterns with pitch sizes of around 498 nm were produced. This can be confirmed by the equation stated below, where the theoretical size of the pitch from Eq. (1) was 497 nm for θ of 15°.

$$\Lambda = \frac{\lambda}{2\sin\theta} \tag{1}$$

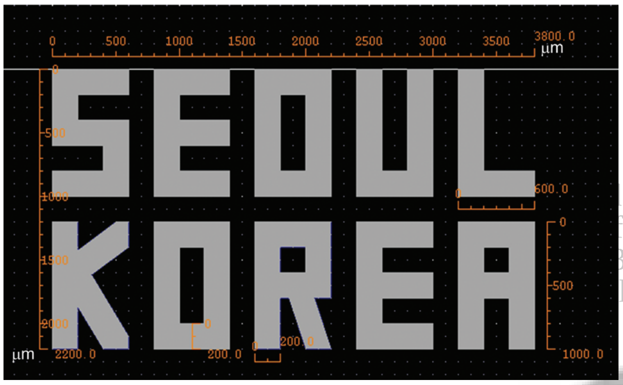

Fig. 4. Design of the photolithography mask.

where Λ is the pitch size of the pattern, λ is the wavelength of the light source, and θ is the half angle between the two beams.

Prior to the LIL process, the effects of the beam power, with a set energy intensity value, was investigated. Although the exposure time can be reduced by applying increased power, to quicken the LIL process, difficulty in realizing the uniformity of patterns with pitch sizes of around 500 nm for a 20×20 mm area was observed (see Fig. 3). To ensure uniform intensity distribution, a low but sufficient power of around 0.153 mW/cm^2 was applied for the LIL process.

Figure 4 shows the mask design that was used for the photolithography process. By applying the mask, the area within the letters remained with the nanoscale patterns, where the other areas were covered with the photoresist, allowing selective etching of the underlying quartz substrate.

The nanoscale patterns generated on the quartz substrate can be observed from Figure 5. It is apparent that uniform two-dimensional arrays were successively fabricated on the hybrid mask mold. Different areas were observed in random scanning electron microscopy (SEM) images to confirm the uniformity of the patterns. To verify the quality of the patterns, SEM images were taken, with higher

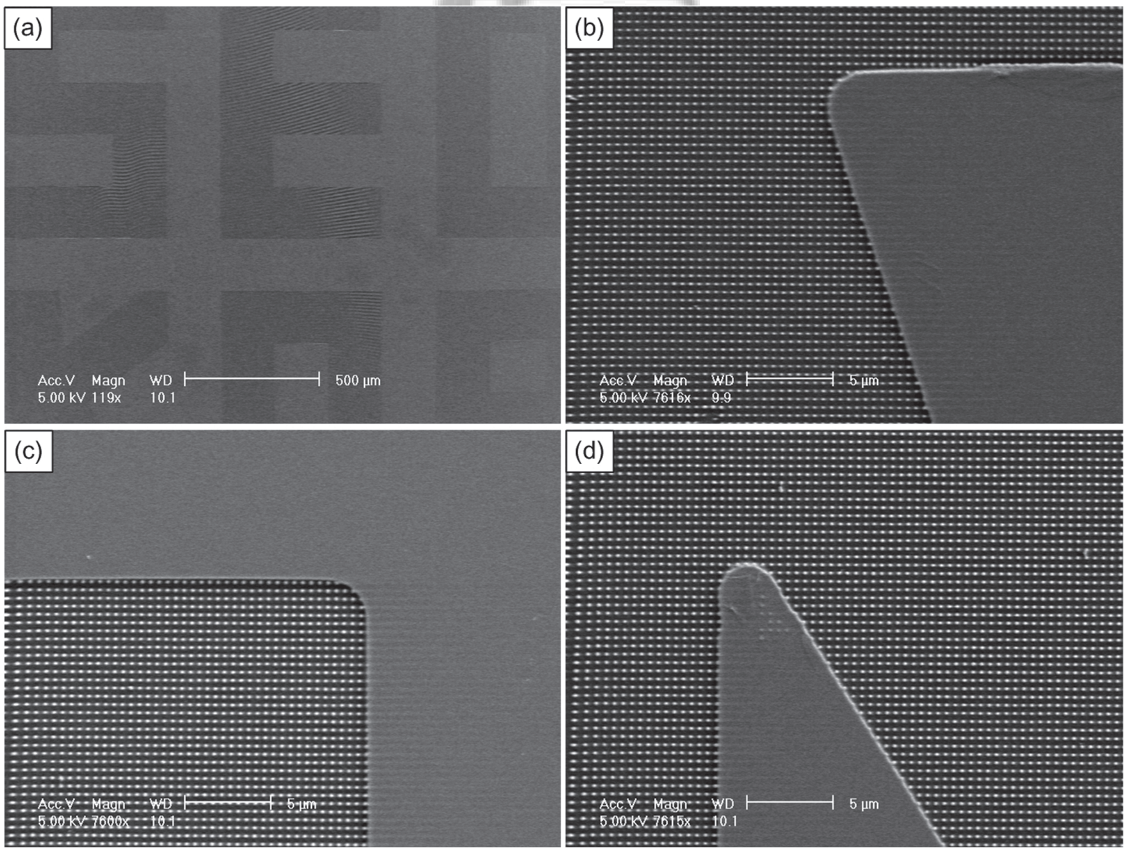

Fig. 5. SEM images of the hybrid mask mold: (a) overview and (b–d) in different areas.

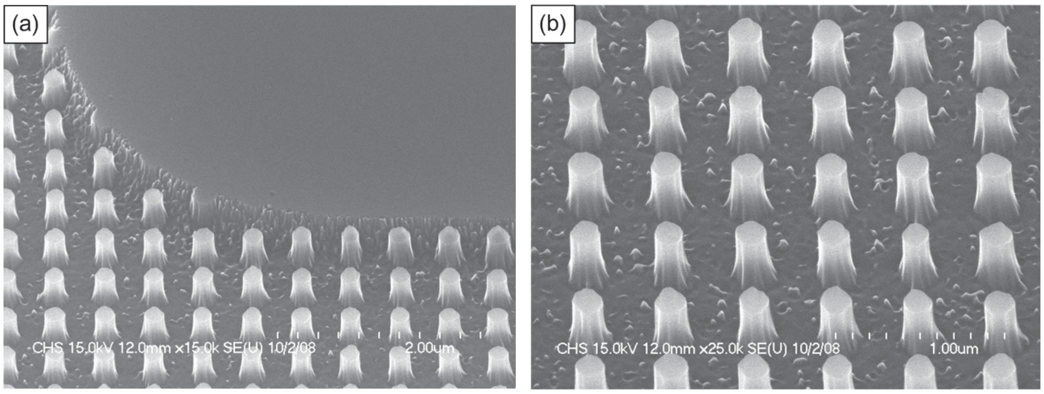

Fig. 6. Magnified SEM images of the hybrid mask mold.

magnification. Exploring the magnified SEM images of the patterns, in Figure 6, the uniformity of the patterns can be clearly seen, even in the boundary areas between the nanoscale and microscale patterns. The quality of the arrays, credited to the successful LIL and RIE conditions, suggested the possibility of applying them to the nanoimprint lithography process. Two-dimensional arrays with pattern sizes of around 180 nm (less than half the pitch size of around 500 nm) and an aspect ratio of around 1.44:1 for each pattern were achieved.

On top of the hybrid mask mold, PDMS was deposited to produce negative patterns, where the elastic properties of PDMS could be advantageous in fabricating replica stamps for nanoimprinting. Figure 7 shows the SEM images of the patterns that were transferred to the manufactured replica of the hybrid mask mold via UV nanoimprint lithography. Although the arrays display a slight non-uniformity compared to the mask mold, sufficient uniformity of the two-dimensional patterns was obtained from the pattern transfer, verifying the effectiveness of using a single-step,

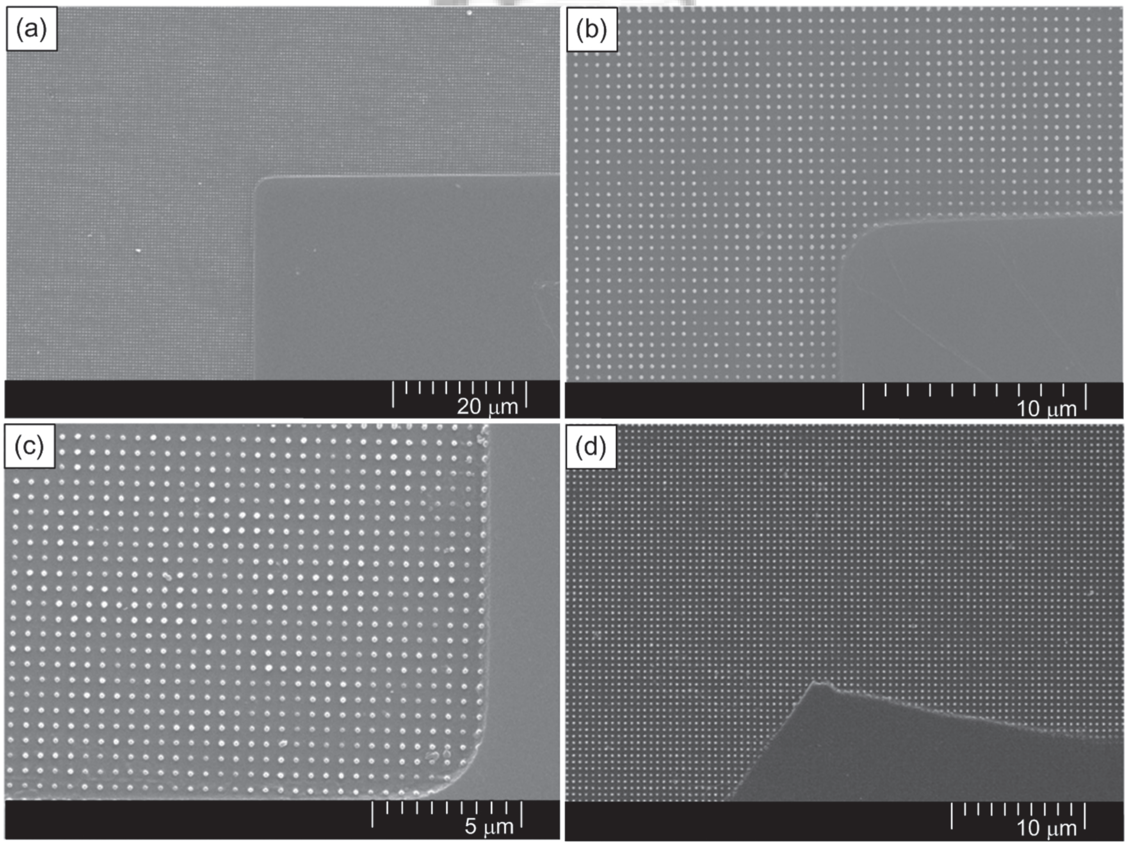

Fig. 7. SEM images of the patterns transferred by nanoimprint lithography.

multiscale patterning technique by combining LIL and photolithography.

4. CONCLUSIONS

A combined LIL and photolithography technique was developed for the fabrication of a hybrid mask mold for nanoimprint lithography process. The technique addressed the limitations of nanoimprint lithography and LIL: the stamp fabrication issue and the non-selectivity of the patterns, respectively. The successful fabrication of a replica mold through nanoimprint lithography via pattern transfer using PDMS was presented. Although LIL has other limitations, especially in terms of pattern resolution, the possibility of selective patterning, which could be developed into single-step patterning through the integration of microscale and nanoscale patterns, could lead to various applications, especially for device production.

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