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# Generation of Various Micropattern Using Microlens Projection Photolithography

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**ABSTRACT**
This paper discusses about review of various process for microlens array fabrication and their application in microlens projection photolithography. Microlens array fabricated by excimer laser machining used in photolithography to produce arrays of microstructures in photoresist. In this technique, the uniform UV illumination is used for exposure and by using a single mask with a single microlens array this system can produce arrays of micropattern in photoresist with a single exposure, which is very useful for mass production. Generated micropatterns can have 3D and uniform image by using a gray-scale mask. Multiple exposure with multiple mask can generate modified and combined pattern on the resist. This technique can generate microstructure with submicron resolution.

Keywords: Microlens array, photolithography, microstructure, excimer laser.

## 1. Introduction

Now a day, microlens arrays have become important optical elements that play a crucial role in advanced micro-optical devices and systems which are being used in optical data storage, digital display, optical communication and so on. Different technologies have been developed for the fabrication of microlens arrays. Some conventional methods used are listed as photoresist thermal reflow [1], photo thermal method [2], photo-polymer etching [3], micro-jet method [4], and micro-molding or hot embossing method [5]. Although the above-mentioned methods are widely used, the common problem for these methods is that the microlens surface profile is not controlled accurately as well as unexpected surface roughness. To fabricate a microlens array with better surface profile and roughness, excimer laser micromachining integrated with a planetary contour scanning method is developed [6]. But the filling factor of arrayed microlenses is limited and it cannot be used in mass production so the efficiency of this method is low. Later, the above method was upgraded into excimer laser dragging method for fabricating varieties of microstructures with arrays based on mask projection and mask/sample movement methods [7], [8]. Common excimer laser KrF (248nm) with wavelength in UV region is used for those machining. The process for material removal by excimer laser is through thermal ablation and/or photo ablation of the materials, i.e. the covalence bonding of the material is broken and vaporized by each laser pulse. The covalence bonding energy of polymer material is relatively low and it has good optical properties so it is suitable for excimer laser micromachining, and hence the photo-ablation mechanism can dominate the material removal [9], [10]. In this method less thermal effect is involved when the laser source can directly break the covalence bonding between polymer molecules, so smooth machined surface can be easily obtained [11].

A simple photolithography method has been discussed in this paper that uses arrays of microlenses to generate arrays of micropatterns with submicron resolution. Conventional lithography techniques form a single image for each exposure and require precision optical systems, expensive apparatus, chrome masks & steppers. Microlens array photolithography (MAP) can generate: (1) array of images by a single exposure because each lens forms an image of photomask. (2) simple repetitive features with minimal equipment & inexpensive masks. (3) Image can connect & overlap to generate varieties pattern. (4) patterns can have symmetries and periodicities. (5) pattern size as small as 500nm. This technique includes collimated flood illumination and masked illumination method which can produce arrays of repetitive micropatterns with shape same as mask pattern. The array of microlenses produce images of bright patterns of the mask and projects an array of size-reduced micropatterns onto the resist layer [12].

## 2. Experimental setup

Those experiments have been divided into two sections and some subsections:

2.1 Fabrication of plano-convex microlenses array

In the following subsection some methods have been discussed to fabricate plano-convex aspheric microlens array.

(1) Excimer laser planetary contour scanning method

Excimer laser micromachining with the planetary contour scanning method can accurately achieve pre-designed axially symmetrical 3D microstructures. This method based on the concept of machining probability and integration of both rotation and revolution of samples, and hence the machined surface profiles can be very accurate and smooth. The machining system includes a KrF (248nm) excimer laser, optical components for shaping laser beam, a 4-axis servo-

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controlled stage movement, and a personal computer for system control [6]. The machining pattern depends on the window opening profile in the photo-mask shown in Fig.1. Since each single laser pulse removes a certain amount of sample material form object, the machining depth depends on the laser fluence and sample material properties. To fabricate 3D microlens, sample is moved by 4-axis stage system and synchronized with laser pulse firing sequences so that laser energy distributes uniformly on object surface. The machining profile of microlens can be directly observed by zoo lens microscope. Fig.1 shows a photo-mask with a typical window-opening pattern for fabrication of single microlens and Fig.2 shows the procedure for fabricating arrays of microlens.

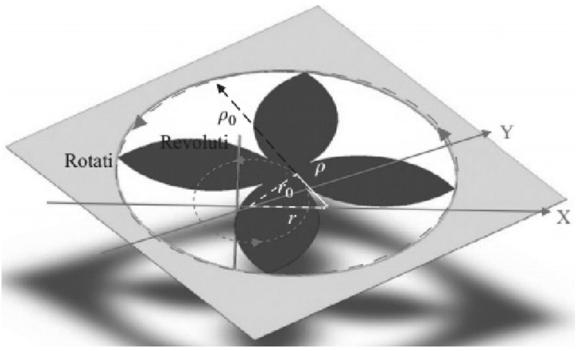


**Fig. 1** Excimer laser machining of microlens using a planetary contour scanning method [6].

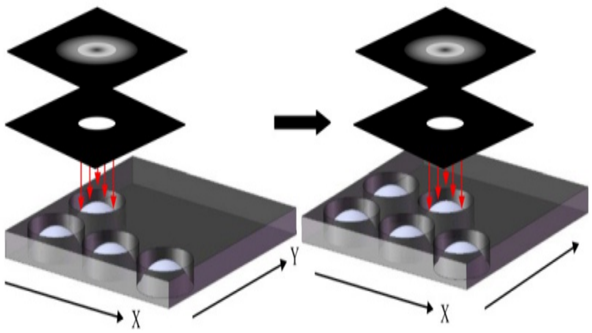


**Fig. 2** The steps for fabricating an array of micro-lenses.

(2) Excimer laser dragging method

This method represents an improved excimer laser micromachining method over the planetary contour scanning method for fabricating arrayed microstructures with a predesigned surface profile. This method is developed from a conventional biaxial laser dragging method. The excimer laser with stage system used in this method is same as previous method. A contour mask, called binary photo mask with a polynomial designed pattern through which laser light is passed and the pattern is made on the object surface along with a programmed scanning path. So the overall or overlapped laser energy projected on the sample surface has a predesigned spatial distribution. If the scanning paths are just straight lines and one direction only then one can get 2D microstructure. Since contour mask contains periodic patterns so scanning from another direction perpendicular to the first line is superimposed each other to create arrayed 3D microstructures in a very straightforward way known as the excimer laser dragging method [13]. Fig. 3 shows a rectangular array of plano-convex 3D microlens obtained by a contour mask with biaxial (x-y) laser line scanning/dragging method. An array of 5×5 microlenses with aperture sizes of 100μm with pitch 100 μm and a designed aspheric profile are obtained experimentally. The machined surface profiles are closely matched to desired ones with a deviation below 1 μm and the average surface roughness around 5 nm. The optical performance of the machined microlens array for minimizing the focal spot sizes are measured which approach to optical diffraction limit [11].

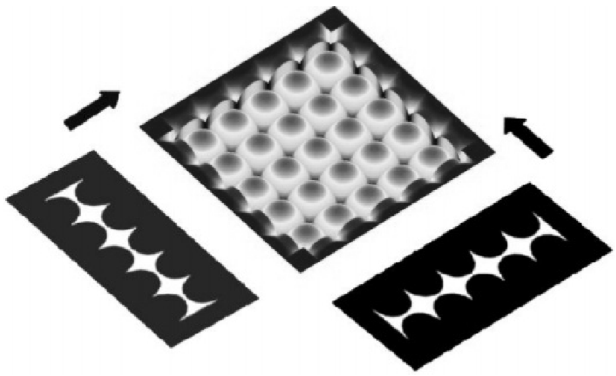

**Fig. 3** Excimer laser machining with a contour mask and biaxial laser dragging method for fabricating arrayed microlens [11].

2.2 Microlens Projection Photolithography

In the following subsections, some experimental setup and methods about microlens projection photolithography have been discussed.

(1) Microlens lithography using collimated illumination

This method depends on the shapes and profiles of the microlens arrays to control the irradiance distribution of the optical micropatterns [12]. It has very simple optical setup which includes a microlens array attach with photoresist by PDMS. The thickness of PDMS maintains the focal length of microlens so that each microlens can make pattern in the image plane. Fig. 4 shows the optical setup for the microlens lithography using collimated illumination. The micropatterns produced by this technique depend on three factors: (i) lenses size, shape and profile, (ii) image distance and (iii) lens refractive index. The patterns produced by this method are uniform over the whole illuminated area. Those uniform micropatterns are generated over areas of 10 $cm^2$ by a single exposure using microlens array with sizes more than 1μm.

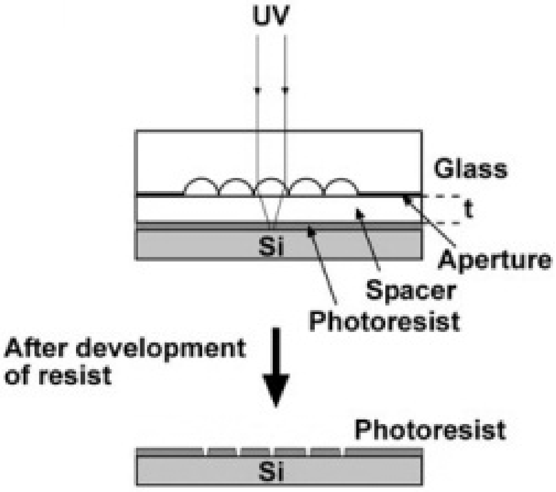


**Fig. 4** Arrays of small holes in photoresist are fabricated by collimated flood illumination [12].

(2) Microlens lithography using patterned illumination
This method has simple equipment for optical setup which includes a UV illumination source, a photomask, a microlens array, PDMS for positions microlens array at a focal length distance and a photoresist. An overhead transparency projector or a UV lamp is used as a light source for the illumination system or exposure. The mask which is patterned on photoresist is first designed with CAD software and then printed onto a transparency paper using a desktop printer. An optical diffuser such as ground glass is placed in front of the projector to homogenize the illumination. The diffuser scatters the illumination from the light source and produces a uniform illumination. This illumination passes through the clear areas of the transparency mask. The microlenses receive the patterned illumination and project an array of micropatterns on the photoresist surface. Fig. 5 illustrates the optical system for microlens projection photolithography.

The transparency mask was placed on top of the Fresnel lens of the projector which acts as a condenser lens that converge the illumination onto the image plane and generates a bright illuminated area on this plane. The image plane is about 40–60 cm from the Fresnel lens, depending on projector design. The lens array and the photoresist are positioned with PDMS spacer to patterned illumination into the image plane. For a resist layer with a thickness of~400 nm, the exposure took between 10 s to 5 min. The membrane is removed from the resist after exposure, and the resist is developed in a sodium hydroxide solution. The surface topology of the photoresist is examined with a scanning electron microscope [12].

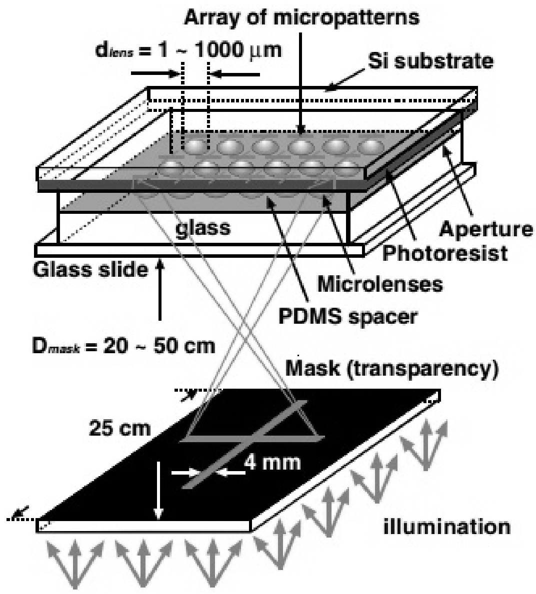


**Fig. 5** Optical system for microlens projection lithography with masked illumination [12].

**3. Result and discussion**

3.1 Micropatterns produced by collimated flood illumination
Microlens arrays under flood illumination can generate arrays of uniform micropatterns over the entire illuminated area more than 10 cm$^2$ [14]. The micropatterns shown in Fig. 6 are produced with a diameter of 1.5 μm lens array.

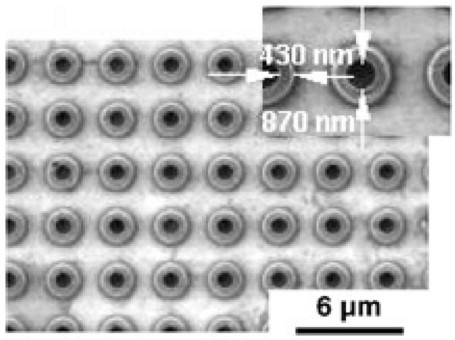


**Fig. 6** An array of circular rings produced by 1.5 μm microlens array [12].

3.2 Micropattern using arrays of plano-convex microlenses
Fig. 7(a) and 7(b) illustrate two micropatterns generated by 10 μm lens array. Micron and submicron scale patterns can be achieved by arrays of plano-convex microlenses. Demagnification i.e. the size reduction of the mask on photoresist is more than 1000 [12].

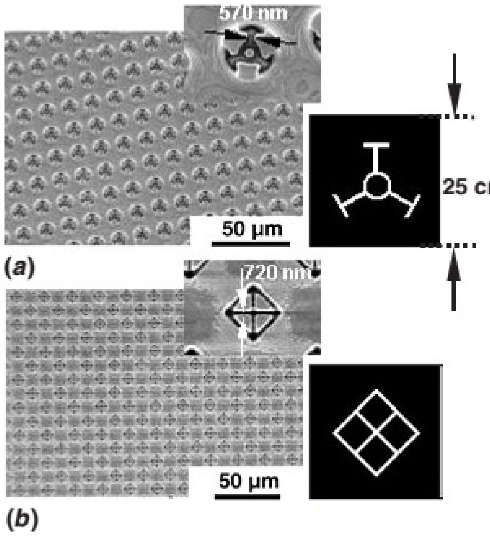


**Fig. 7(a) and 7(b)** SEM images of those patterns produced by an array of 10 µm plano-convex microlenses [12].

This technique can also generate arrays of complicated patterns with larger sizes of microlenses. Figures-8(a) and 8(b) show the patterns generated by square arrays of 40 µm and 100 µm lenses respectively. Fig. 8(a) shows high quality micropatterns of the logo 'VERITAS' by array of 40 µm lenses. The circuit type pattern shown in Fig. 8(b) is produced by an array of 100 µm square lenses. So this method can be applicable in the field of micro-electro mechanical systems (MEMS).

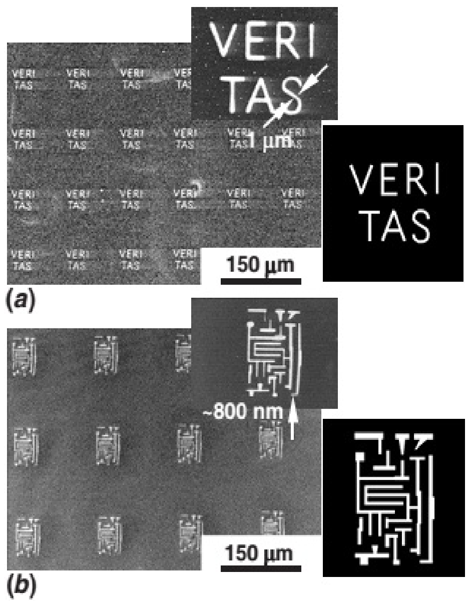


**Fig. 8** SEM images of complicated patterns produced by different microlens arrays. (a) by arrays of 40 µm lenses. (b) by arrays of 100 µm lenses [12].

By this technique, generated micropatterns can be connected and rotated with horizontal axis. When the size of cross mask (l), shown in Fig. 9, is larger than a critical length lc (l>lc=10cm), the reduced micropatterns overlapped with each other to form a connected and continuous pattern [15]. Micropatterns can be rotated with high-symmetry directions at 27° and 45° and highest periodicity at 27°. Fig. 9(a) and 9(b) illustrate the separated images and connected images respectively.

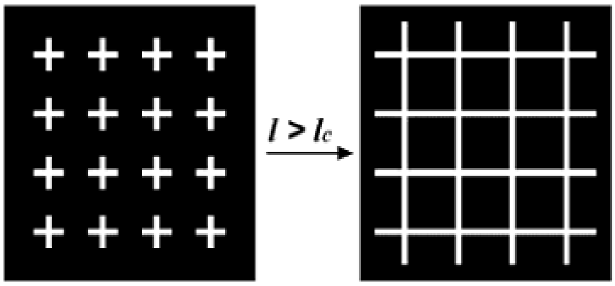


**Fig. 9(a) and 9(b)** separated and connected pattern produced by an array of 100µm plano-convex microlenses [15].

3.3 Micropatterns correction with gray-scale masks

Gray scale mask has two advantages over the binary mask: (i) reduce distortion of 2D micropatterns caused by diffraction and proximity effects [16]. (ii) generate 3D microstructures. The patterns with gray-scale opacity on the binary masks can be printed easily. Fig. 10(a) and 10(b) illustrate a comparison of two cross-shaped micropatterns arrays that is generated using a binary mask and gray-scale mask. The images of the cross-shaped micropatterns with binary mask is not uniform across line-width which is broadened at centre and tapered at the corner as shown in Fig. 10(a). By contrast, gray-scale mask produces an array of crosses with more uniform line-width as shown in Fig. 10(b).

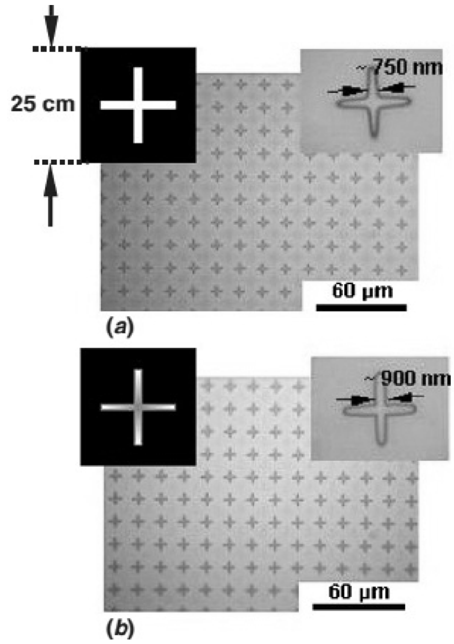


**Fig. 10** SEM images of cross-shaped patterns produced by an array of 10 µm lenses. (a) using a binary mask (b) using a gray-scale mask [12].

3.4 Micropatterns using multiple exposure with multiple mask

Multiple exposures with multiple masks are used to modify microstructures as like as post processing. In this process, different mask is used for each exposure without changing the position of lens array and photoresist. The profile of developed resist shows a modified, combined pattern of all the masks. Fig. 11(a) shows an array of hexagonal microstructures produced by gray-scale mask with single exposure. Then another exposure with binary mask that has a binary pattern of a tripole, shown in Fig. 11(b), generates an array of connected microstructures using two masks with double exposures. But it has a limitation that fine modification of a microstructure can be done only at specific locations.

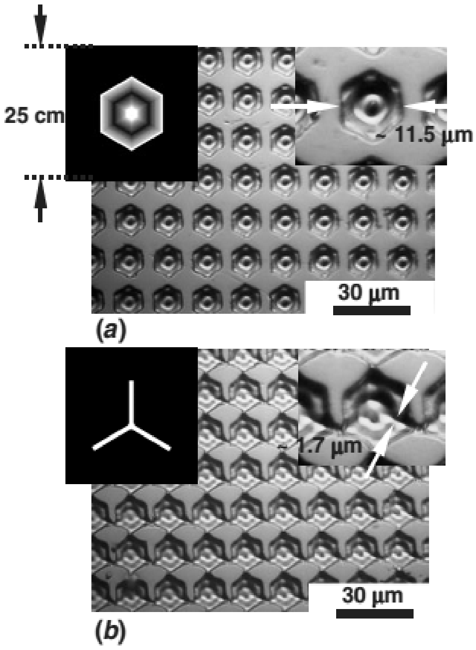


**Fig. 11** SEM image of micropatterns using two exposures with two masks. (a) array of hexagonal microstructures using a gray-scale mask. (b) array of connected hexagonal microstructures generated after second exposure through a binary mask [12].

**4. Conclusion**

This work demonstrates that a single microlens array can produce varieties of structures by a single mask. Microlens array is fabricated by planetary contour scanning method. Since it has limitation to fabricate large microlens arrays so excimer laser dragging method is also presented which can create 100x100 lens array [11]. Various types of microlens projection photolithography techniques are also presented which have very simple optical setup, low-cost and microstructure having dimensions from 300 nm to more than 10 µm. Micropatterns fabrication with two types of illumination named as collimated flood illumination and patterned illumination is presented. In the result and discussion section, SEM image of various fabricated micropatterns such as simple, complicated and connected pattern are illustrated by various figures. Resulted micropatterns can be modified by gray scale mask and multiple exposures with multiple masks. This technique will be useful in applications of repetitive microstructures: e.g., frequency-selective surfaces, flat-panel displays, information storage devices, sensor arrays and array based bio-systems.

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