ACTIVE MASK UV LITHOGRAPHY SYSTME FOR MEMS AND µTAS APPLICATIONS

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INTRODUCTION

Rapid and accurate fabrication of 3D microstructures is very important for developing devices that are used in microelectromechanical systems (MEMS) and micro total analysis systems (µTAS). Manufacturing such miniaturized 3D devices is typically accomplished by complex processes with multiple etching and deposition steps. Since the method requires a repetitive exposure procedure, the preparation of the multiple photomasks and the repetitive exposure procedure prevents the rapid fabrication of 3D microstructures[1,2].

In order to simplify the fabrication process, an active mask fabrication technique for the small-lot production of 3D microstructures is proposed; it is a photolithographic technique that utilizes a liquid crystal device (LCD) as an electrically controllable photomask. The advantages of this system are as follows: The computer-generated photomask serves as an active photomask in the LCD lithography system. The positions of photomasks can be precisely controlled by a unit of the LCD pixel without any mask alignment procedure. This allows the rapid fabrication of microstructures as well.

It is expected that this system will rapidly and precisely fabricate complicated 3D structure such as a µTAS chip and MEMS devices in small-lot production. The production time and cost of microdevices can be improved significantly using this system.

This paper describes the following: 1) development of the LCD mask exposure system with UV light source, 2) experimental confirmation of high resolution such as 11 µm in the case of exposure using grid patterns.

DESIGN OF LCD LITHOGRAPHY SYSTEM

A photolithography system with an LCD as an active mask developed here used a conventional high-pressure mercury lamp as an ultraviolet (UV) light source in order to fabricate microstructures by using commercially available photoresists. The optical configuration of the LCD lithography system was determined from the following experiments. First, the contrast of the LCD mask to the UV light was evaluated as a function of irradiated light intensity. Next, an appropriate incident angle of the UV light for the LCD mask was investigated in order to obtain the highest contrast in the system. We also examined optical aberrations on the image plane of the system with the LCD mask in order to improve the pattern exposure resolution.

Contrast of LCD mask against UV light of 365nm

In the LCD, polysilicon thin-film transistors (TFTs) are used as switching elements for pixels. Therefore, in order to prevent damage to the LCD that must decrease the contrast of the LCD during UV exposure, the UV light irradiation on the TFT substrate part should be reduced[3,4]. In this experiment, we selected the LCD integrated with microlens array, resulting in a high numerical aperture (NA) of more than 54%, which is greater than that of a conventional LCD. This type LCD has an advantage; the microlens decreases the UV light irradiation on the TFT substrate part that will reduce the above problems to a minimum. In addition, the loss of UV light through the LCD mask effectively decreases.

The contrast of the LCD mask against UV light centred at 365 nm selected from a high-pressure mercury lamp (Ushio Inc., SX-UI 500HQ) through an optical filter was investigated under varying irradiation conditions with the basic configuration of an experimental optical setup shown in Fig. 1. Two important factors—light intensity and incident angle—were considered since they would affect the LCD mask contrast. We calculated the LCD mask contrast by using two parameters — I_{255} and I_0; they denote the transmitted light intensity when LCD mask grey levels are of 255 (Open) and 0 (Close), respectively. The contrast was defined as I_{255}/I_0. As shown in Fig. 1, a polarizer changes the polarization of incident light from the mercury lamp into a linearly polarized light. The polarized light is then focused by a lens with a variable aperture and passed through the LCD mask. A pair of polarizers is placed in the orthogonal polarization direction at the front and back of the LCD mask.

Fig. 2 shows the influence of light intensity on LCD mask contrast as a function of F-number. The F-number (F = f/D) is defined as the ratio of aperture diameter (D) to the effective focal length of a lens (f). It expresses the divergence angle of focused light rays, that is, an increase in the F-number will decrease the divergence angle. An F-number of 5.7 gives approximately 5° divergence angle with respect to an optical axis, which is a maximum value in this experiment. The data (denoted by a △ symbol) were taken by changing the optical density of a neutral density (ND) filter at the same aperture diameter in order to change the light intensity only. The mask contrast slightly increased with an decrease in the light intensity less than 150 mW/cm^2.

On the other hand, the LCD mask contrast (denoted by a ○ symbol) were measured at varying F-numbers with changing the aperture diameter. The mask contrast increased markedly with an decrease in the light intensity, where the F-number increased simultaneously. At a light intensity of 150 mW/cm^2, the mask contrast at F = 13.4 was approximately three times larger than that at F = 5.7. These results suggest that the effect of the divergence angle corresponding to the F-number on the improvement in the mask contrast was greater than that of the light intensity. Therefore, the perpendicular incident direction to the LCD mask with a well-collimated incident light is required to achieve high LCD mask contrast.

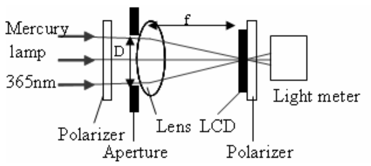


Fig. 1 Experimental setup for characterization of LCD mask contrast.

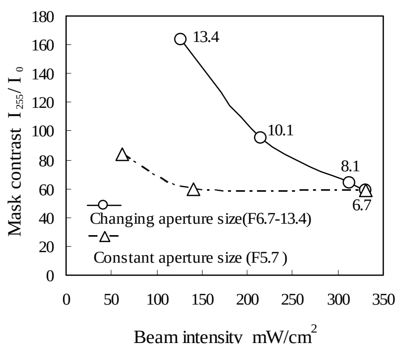


Fig. 2 Influence of light intensity on LCD mask contrast as a function of F-number.

OPTICAL DESIGN OF UV LITHOGRAPHY SYSTEM WITH LCD ACTIVE MASK

As mentioned above, a pattern projection system with high LCD mask contrast could be achieved by using collimated UV light that perpendicularly illuminated the LCD mask as well as low light intensity. Based on this concept, we designed the optical configuration of an UV lithography system with an LCD active mask as shown in Fig. 3. By applying a reduction optical system, the LCD mask can be placed just behind the mercury lamp, and consequently, it will be illuminated by well-collimated light with relatively low intensity. The energy density of the light passed through the LCD mask can be intensified on an exposure plane by the reduction optics. This will allow patterning conventional UV-sensitive photoresists. Moreover, the pattern exposure resolution can be improved because the reduction image of the mask pattern displayed on the LCD is projected on the exposure plane.

The optical system was composed of three parts, namely, a uniform irradiation optical system that generates collimated light with a low

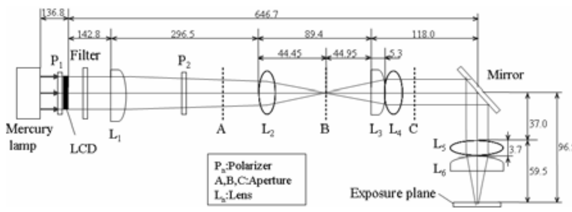


Fig. 3. Optical configuration of the LCD lithography experimental system.

energy density, reduction optical system that reduces the LCD mask pattern at 15%, and relay lens optical system that transfers the LCD mask image to an exposure plane. A wavelength of 365 nm was selected from the mercury lamp using an optical filter with a transmittance of 82.7% before illuminating the LCD mask. The lens arrangement and specifications were determined by considering the balance of optical aberrations based on ray-tracing simulation results. In order to reduce the light absorbance to a minimum, we used anti-reflection coated lenses with a transmittance of 99.0% and a mirror with a reflectance of 99.0 % at 365 nm. In this system, the LCD mask, consisting of a pair of polarizers and the LCD itself, showed very low transparency at 365 nm, resulting in a transmittance of only 1.1%. As a result, the overall transmittance of the optical system (from the mercury lamp to the exposure plane) was estimated to be as low as 0.8%.

However, as the LCD lithography system designed here is a projection system with a 6.5:1 reduction, the UV light intensity on the exposure plane can be maintained to be approximately 35% of that of the mercury lamp.

EVALUATION OF PATTERN RESOLUTION ON LCD LITHOGRAPHY SYSTEM

Fundamental experiments were conducted by using a binary mask image displayed on the LCD in order to achieve high resolution on the LCD lithography system. In this chapter, we discuss the effect of apertures on pattern exposure resolution. Three apertures A, B and C were set as shown in Fig. 3. They will strongly depend on optical aberrations on an exposure plane.

Effect of apertures on pattern exposure resolution

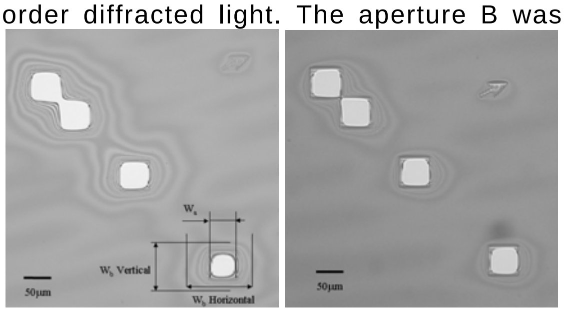
A computer generated mask image on the LCD composed of four square patterns with a size of 19×19 pixels (342×342 μm^2). The squares are located diagonally with a gradually increasing interval. This mask image is reduced by 15%, and consequently, the size of each square pattern will be of 52.3×52.3 μm^2 on the exposure plane. Fig. 4(a) shows a typical photoresist pattern formed by using the LCD mask image without any aperture on the LCD lithography system. A positive photoresist (Tokyo Ohka Kogyo Co. Ltd., OFPR-800) layer with a thickness of about 1.4 μm was spin-coated onto a silicon substrate, and then exposed by 365 nm UV light. The resulting square-shaped photoresist patterns (in width Wa) were equivalent to the transparent image area of the LCD mask. However, in the neighbourhood of each square pattern, interference fringes were observed. Since the interference fringes are originated in the change in photoresist thickness, this region (in width Wb) can be also considered as a light irradiated area, but the photoresist was still remained in a development process probably due to underexposure. Such geometric error is mainly caused by optical aberrations on the exposure plane. Therefore, the pattern resolution must improve as the width W_b of the exposed area approaches the width W_a of the patterned area by adjusting the position and diameter of the apertures.

The exposed area did not change despite the addition of aperture A. It did not change even when the aperture diameter of B was decreased. However, the exposure area decreased with the aperture diameter of C.

Exposure results obtained without the aperture C has an interference fringe The resolution is considered to improve as the area of Wb approaches that of Wa. The resolution of pattern exposure is optimum when the aperture C with a diameter of 8 mm is used; in this case the exposure area is the minimum.

From the above result, it was confirmed that the exposure area could be optimized by adjusting the aperture diameter of C. Therefore, the aperture diameter of C was the dominant parameter for achieving the appropriate irradiation conditions.

The aperture A was considered to control the light amount and remove the high order diffracted light. The aperture B was



(a) (b)

Fig. 4. Typical positive photoresist patterns formed by using LCD mask with LCD lithography system: (a) Exposed at exposure energy of 66 mJ/cm^2 (0.168 mW/cm^2 × 390 s) without any aperture; (b) exposed at exposure energy of 15 mJ/cm^2 (0.025mW/cm^2 × 600 s) with 8mm-diameter aperture C.

considered to remove the stray light. The aperture C was considered to decide the resolution of reduction optical system. However the reduction optical system had long optical path from lens L1 to L3, the frame of lens worked as well as the aperture A and B. On the contrary the aperture C could control the angle of the field on relay lens imaging system, that is composed from lens L3 to L6, at the behind of lens L4. The resolution thus depended on the size of the aperture C.

<u>Evaluation of resolution using line and check patterns with different aperture sizes of A, B and C</u>

Line pattern were produced in order to investigate the resolution by using the reduction optical system. The line pattern with a 10 μm gap could be fabricated when the aperture C was set to a diameter of 8 mm. The pattern resolution corresponded to the contrast of light intensity between the exposed area and its surrounding area. The resolution decreased significantly with an increase in the exposure line width because of overexposure.

Fig. 5 shows the fabrication result of the line pattern with a width of 10.8 μm. The diameter of C was 8 mm. The resolution did not improve with any change at B. The highest mask contrast was obtained by adjusting C of 8 mm in the designed optical system.

It was confirmed that the line pattern with a line width of 10.8 μm could be precisely fabricated using OFPR-800. It was confirmed that our designed optical system, which uses UV light as a light source, was useful for 2D device fabrication.

CONCLUSION

In this study, we designed the LCD mask exposure system for applying the LCD as a UV photomask. The patterning resolution of the LCD mask was evaluated. It was experimentally confirmed that the line pattern of 10 μm in width could be fabricated by using the developed system.

The experimental results are summarized as follows.

(1) The mask contrast lowered with an increase in the angle of light emitted in the LCD. In particular, the contrast decreased rapidly when the range of the incident light angle was greater than 5°.

(2) The patterning resolution of the reduction optical system without any aperture was 48.6 μm (18 pixels). The finest pattern could be fabricated by installing the aperture C of 8 mm. The resolution was 10.8 μm (4 pixels) in the line width and 5.4 μm (2 pixels) in the line space.

It was expected that this technique could be applied to the fabrication of μTAS chips such as the flow channel with tapered shape. 3D MEMS devices could also be fabricated without the multistep procedure. In addition, this technique could be applied widely for controlling the lighting area and light intensity distribution in order to control various photochemical reactions. This technique is expected to be applied for the synthesis technology of DNA chip production.

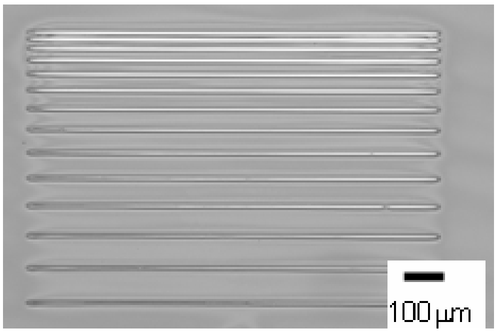


Fig. 5 Line pattern with a width of 10.8 μm width at 12.9 mJ/cm2

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