Micro-Stereolithography of Dot Shapes for Lightguide Using LCD Grayscale Mask

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Abstract
In this study, a novel microfabrication method that is micro-stereolithography using a LCD grayscale mask has been proposed. Light transmittance distribution with the LCD grayscale mask can be varied with that level of grayscale. Accordingly, a grayscale pattern of the LCD mask is responsible for an intensity distribution of an exposure pattern. This method has realized a fabrication of the prismatic shaped dot with the size of 18μm in width and 15μm in height. Consequently, the feasibility of the microfabrication was experimentally confirmed for the lightguide with high light guiding efficiency used in LCD backlight unit.

Keyword : micro-stereolithography, LCD grayscale mask, prismatic shaped dot, lightguide

1. Introduction
A lightguide for small size liquid crystal display (LCD) backlight unit has an array of patterned dots on the bottom surface. These dots make the incident light scatter upward. Currently, the most common shape of the dots is a dome shape whose diameter is from 50μm to 200μm. However, light guiding efficiency of the lightguide with dome shaped dots is low because the dome shaped dots scatter the incident light toward various directions. It is, then, required to investigate the optimal design of the dot in order to increase the light guiding efficiency. Recently, we have attempted to fabricate the lightguide with prismatic shaped dots whose size is 10~20μm in width, 5~20μm in height and 25~50μm in depth. An illustration of the prismatic shaped dot is shown in Fig. 1. Using this prismatic shaped dot, a reflected light direction can be adjusted with an angle of a gradient of the dot, so that the light guiding efficiency could be largely increased.

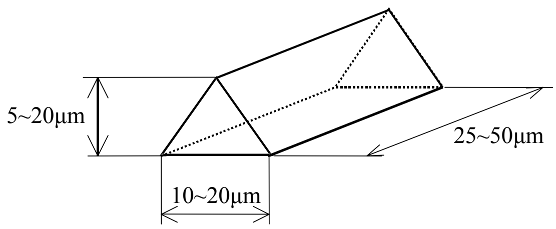

Fig. 1 Prismatic shaped dot for the lightguide

Regarding a manufacturing method of the lightguide, injection molding has been employed because of its high productivity and the dots are formed at the same time by using a stamper. However, conventional fabrication method for the stamper such as an isotropic etching is not suitable for the fabrication of the stamper with the prismatic shaped dots in array with varying its shape. In this study, a novel microfabrication method that is micro-stereolithography using a LCD grayscale mask has been proposed for the fabrication of the prismatic shaped dots for the stamper. The fabricated resist pattern can be transferred into a mold by using Ni electroforming technique. As a result, the fabrication of the stamper with the prismatic shaped dots is realized. In this report, the fabrication of the prismatic shaped dots is especially focused, by means of micro-stereolithography using a LCD grayscale mask.

2. Micro-stereolithography using LCD grayscale mask
Micro-stereolithography using LCD grayscale mask is a novel mask-exposure stereolithography, where LCD is employed as a mask for displaying grayscale image. Light transmittance at each pixel of the LCD can be varied with level of grayscale. Accordingly, a grayscale pattern of the LCD mask is responsible for an

intensity distribution of an exposure pattern. Because a height of the photoreacted part depends on exposure energy, a 3D structure can be fabricated with a single exposure. A schematic diagram of this method is illustrated in Fig. 2.

A remarkable characteristic of this method is that the grayscale distribution of the LCD mask can be flexibly varied for fabrication of designed objects. Therefore, this method is superior to the other grayscale lithography[1][2] in terms of mask changing. Besides, there is a possibility of wide-range exposure in case of integrating step-and-repeat process, which is used in semiconductor exposure systems, into this method.

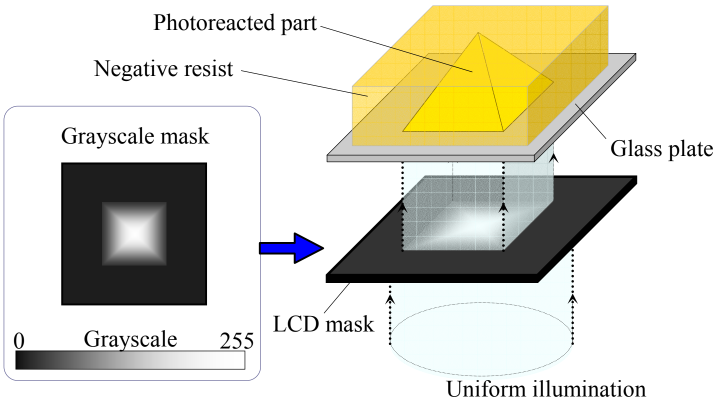

Fig. 2 Schematic diagram of micro-lithography using LCD grayscale mask

3. Experimental setup

Fig. 3 shows the schematic diagram of the experimental setup. The light source is the Hg-Xe lamp and its shortest peak wavelength is 405 nm. The negative resist is formed on the glass substrate as a photosensitive material by spin-coating method, and its thickness is 40μm. The reduction ratio of the lens projection system is 16.6%. Square size of one LCD pixel is $19.5\times19.5\mu m^2$ and the exposed size is reduced to $3.3\times3.3\mu m^2$ by using the lens system. The mask pattern is projected on the bottom surface of the negative resist. The LCD mask has 256 levels of grayscale.

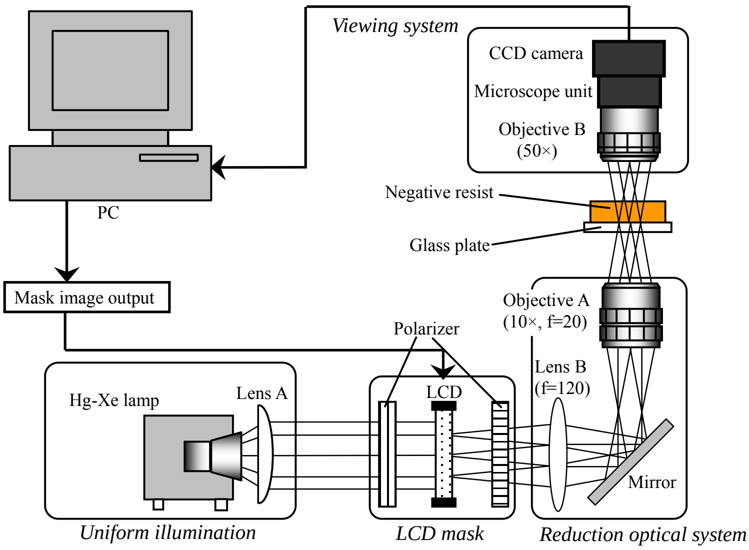

Fig. 3 Experimental setup of micro-stereolithography using LCD grayscale mask

4. Grayscale mask design

In this fabrication method, the fabricated pattern depends strongly on the grayscale distribution of the LCD mask. In the following, grayscale mask design for the prismatic shaped dot is described.

4.1 Photosensitive characteristic of negative resist

Applying Beer-Lambert law to stereolithgraphy technique, a relationship between height (H) of a photoreacted part and exposure energy (E) is shown by the equation

$$H = D_p \ln\left(\frac{E}{E_c}\right) \qquad (1)$$

where D_p is "penetration depth" and E_c is "critical threshold exposure" [3]. Both D_p and E_c are photosensitive material constants. This equation indicates a photosensitive characteristic of the negative resist. That is one of the essential elements of the grayscale mask design.

4.2 Light transmittance characteristic of LCD mask

Fig. 4 shows a relationship between grayscale level (G_s) of the LCD mask and exposure intensity (I) on the focal plane. The solid line is the exponential fit where G_s is between 150 and 210. This approximate exponential function is shown by the equation

$$I = k_1 \exp(k_2 G_s) \qquad (2)$$

where k_1 and k_2 are constants; k_1=6.82×10^{-3} and k_2=3.75×10^{-2}.

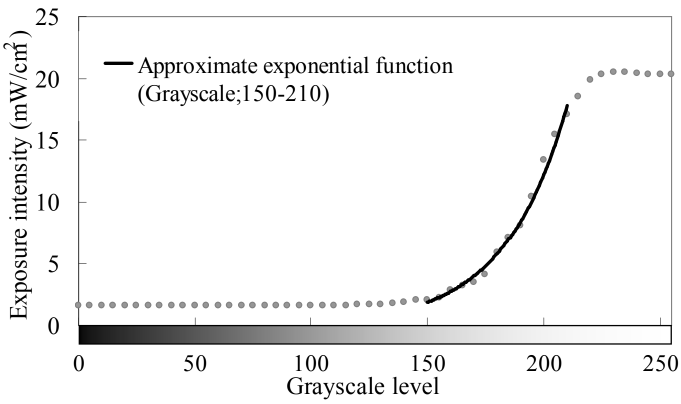

Fig.4 Relationship between Grayscale and Exposure intensity

4.3 Grayscale mask for prismatic shaped dot

The prismatic shaped dot has 2 inclined planes. Considering the height of the photoreacted part at every pixel on the focal plane (xy-plane), the height proportionally increases to x (or y). A design of the grayscale mask for this photosensitive condition is achieved using grayscale levels between 150 and 210 which region can be approximated by the exponential function (2). The equation (1) can be reformed to equation (3) by substituting the equation (2) and $E=I\cdot t$, where t is exposure time.

$$H = k_2 D_p G_s + D_p \ln\left(\frac{k_1 t}{E_c}\right) \qquad (3)$$

The exposure time is constant in the single exposure process, therefore variable parameters are only G_s. Thus H is a linear function of G_s. A representative grayscale mask using grayscale levels between 150 and 210 is shown in Fig. 5. It becomes possible to adjust an angle of the gradient of the dot by changing the slops of the grayscale distribution.

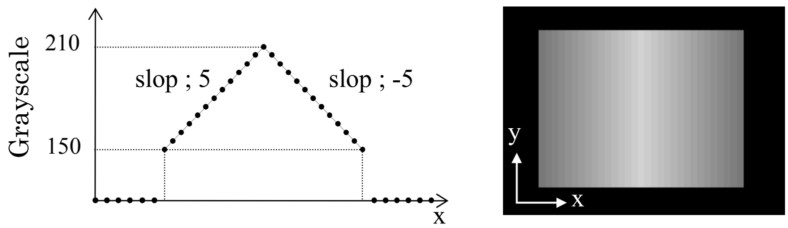

Fig. 5 Grayscale mask using grayscale levels between 150 and 210 with constant slopes

5. Fabrication of prismatic shaped dots

Using the mask design method described above, the fabrication of the prismatic shaped dot was performed. In this case, the grayscale level of the center section of the mask was set 230 for emphasizing the edge of the prismatic shaped dot. The exposure conditions were followings: Exposure intensity, where grayscale level was 255, was 20.4mJ/cm^2. Exposure time was 75sec. The development condition was that the developer was vibrated in ultrasonic wave using an ultrasonic cleaner and the development time was 5 minutes. The SEM image of the fabrication result is shown in Fig. 6. Size of this dot is 18μm in width and 15μm in height, and the angle of the gradient is 60º. This dot is enough small to be applied as the dot for the lightguide.

In order to fabricate the prismatic shaped dot whose edge is emphasized, it is necessary to remove a thin resist layer which covers a fabricated structure even after the development. The ultrasonic agitation seems to be effective to remove the disturbing layer.

A number of the dots can be fabricated with a single exposure using full area of the LCD mask (1280pixel×1024pixel) because only 31pixel×21pixel at the LCD mask were used in the fabrication process for the prismatic shaped dot shown in Fig. 6. The fabrication of the prismatic shaped dots in various sizes and angles of the gradients was performed as shown Fig. 7 with a single exposure using the grayscale mask which has various grayscale distributions for the dots.

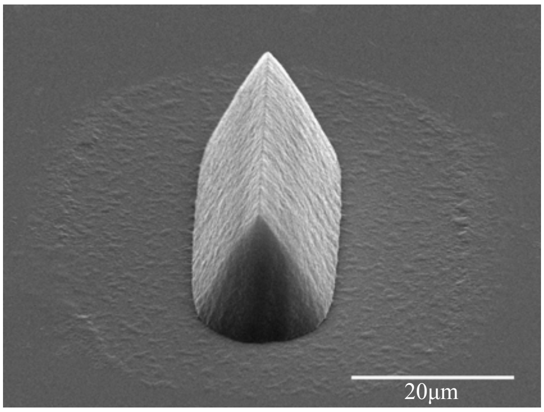

Fig. 6 Prismatic shaped dot; 18μm in width and 15μm in height

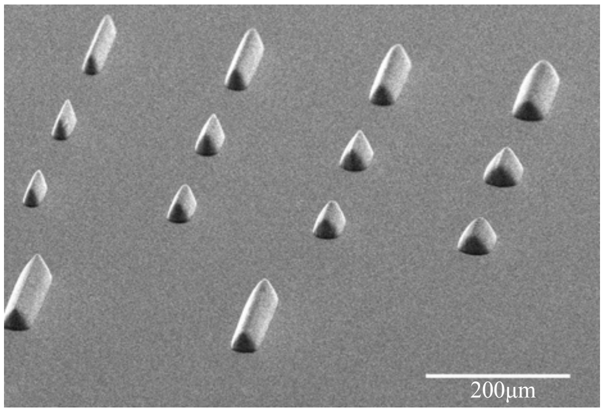

Fig. 7 Prismatic shaped dots in various sizes and angles of the gradients, which were fabricated with a single exposure using grayscale mask.

6. Conclusion

This paper demonstrated the fabrication of the prismatic shaped dot for the lightguide by means of a novel fabrication method which is micro-stereolithography using LCD grayscale mask. Size of this dot is 18μm in width and 15μm in height, and angle of a gradient is 60º. This dot is enough small to be applied as the dot for the lightguide. Consequently, the feasibility of the microfabrication for the high guiding efficiency lightguide was confirmed.

References

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