Square-Aperture Microlens Array Fabrication by the Moving Mask Technology

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ABSTRACT

In this article, we researched on the fabrication of square-aperture microlens array by the moving mask technology, in order to solve the problems that microlens array is difficult to be gained and the traditional circular aperture microlens array has a very low filling factor. The steps of fabrication of microlens array contain mask preparation and photolithograph process. Moreover, photolithograph process includes three steps: photoresist coating, exposure and development. During the exposure process, the mask that we designed previously moves along the X axis and the Y axis, respectively. After developing process, the square-aperture microlens array will be gained. Through further experiments, square-aperture microlens array is applied in dynamic display film which requires microlens array with high filling factors and accurate focal length. In the end, a conclusion is drew that moving mask technology is effective to fabricate microlens array, which has an important meaning in those systems where the loss of optical information needs to be reduced.

INTRODUCTION

Microlens array, including refractive type and diffractive type, whose advantages include miniature size, lightweight and easily integrated, has been applied in a wide range of areas. Since micro-optics was brought forward in 1980s,1 a lot of microlens array’s fabrication methods had been developed.2-4 The melting photoresist method, that is used widely in the world, cannot produce square-aperture with high filling factors and good surfaces precisely.5 In addition, efficiency increasing, cost reduction and quality improvement also need to be taken into consideration in microlens array fabrication.

As an important parameter of microlens array, the filling factor determines the performance in convergence and divergence of light,6 and it is influenced by the surface and arrangement of microlenses. The traditional circular aperture microlens array that is
arranged in orthogonal array has a filling factor of 78.5 percent, and it will be increased to 90.7 percent at most when it is arranged in hexagonal array. Therefore, the filling factor of circular aperture microlens array is restricted to a low value. As a result, how to fabricate microlens array with good surfaces and high filling factors becomes a challenging topic.

In this work, moving mask technology has been used to generate square-aperture microlens array, which not only improves the surface of the microlens array, but also produces square-aperture microlens array with a high filling factor. Theoretically, the square-aperture microlens array has a filling factor of 100 percent, but in fact less than 100 percent and higher than 95 percent experimentally. The square-aperture microlens array will satisfy most systems, such as organic LED lighting system, infrared focal plane photosensitive arrays of infrared detectors, and micro-structure dynamic display film which has been developed rapidly in recent years.

Fabrication of microlens array by moving mask technology includes two steps: mask preparation and photolithograph. In the exposure process of photolithograph, the mask is moving along the X axis and the Y axis in exposure process, respectively. During this process, binary graphics on the mask modulates the energy of ultraviolet light continuously. Importantly, in order to get a continuous exposure distribution on the photoresist surface, we set the moving distance of the mask at an integer multiple of a period of the microlens array. At last, through the developing process, square-aperture microlens array is gained. Moreover, the experimental result is applied in dynamic display film, and clear dynamic display is observed.

**FABRICATION PROCESS**

In respect that characteristics of microlens array are determined by the moving mask to a great extent, the moving mask needs to be programmed and fabricated precisely. After mask preparation, the photolithograph process is carried out in 3 steps: photoresist coating, exposure and development.
Figure 1 indicates that the central distance and the period of square-aperture microlens array are designed to be 50 microns, and the error is supposed to be less than 1 micron. In addition, the focal length is 55 microns and the rise is 6.1 microns. Figure 2 shows the schematic of photolithograph process of moving mask technology.

![Figure 2. Schematic of photolithograph process of the moving mask technology.](image)

According to Figure 2, the photolithograph process is carried out in three steps. In photoresist coating process, photoresist AZ9260 is used as the microlens array’s material. As it shows in Fig.3, the thickness of photoresist spin coating is 8.5 microns. During exposure process, in order to obtain microlens array with correct periods, the moving distance of the mask needs to be set at 50 microns or positive integer times of 50 microns. Besides, the moving distances along X axis and Y axis need to be same. Meanwhile, the exposure also needs to be set at an appropriate value, which is determined by the moving speed of the mask. In this experiment, the moving distance of the mask is actually set at 50 microns, and the moving speed is set at 7 µm/s. In

![Figure 3. The thickness of the photoresist spin coating.](image)
developing process, it is developed for 30 seconds in the mixture of the developer AZ 400K and deionized water at the temperature of 26°C, and the volume ratio of developer AZ 400K to deionized water is 1 to 2.

EXPERIMENTAL RESULT

Figure 4. The surface image of square-aperture microlens array.

Figure 4 shows the surface image of the fabricated microlens array. We obtain that the aperture is squared and periodic. Furthermore, the arrangement of microlens is tight, and the filling factor is over 95 percent. However, the filling factor is less than 100 percent and there are two main causes that bring about the reduction of the filling factor. One of them is that the four corners of the square-aperture microlenses are over developed in developing process. As a result, the four corners aren’t covered with photoresist. The other one is that a few microlens elements in photoresist adhere badly on the substrate and flake off. If the quality of photoresist and substrate is more satisfied, the filling factor of microlens array will be further improved. Figure 5 reveals the specific parameters about the micro-structure of the microlens array.

Figure 5. Parameters about the micro-structure of microlens array.
According to Figure 5, the surface of the microlens array is smooth, and we can get both the period of and the rise of the microlens array. We choose 5 continuous cycles of the fabricated microlens array, which is measured as 253.22 microns in total. Then we calculate the average value of period of the microlens array, which is 50.64 microns. It means the average error is 0.64 micron which is within acceptance. Besides, we get that the rise of the microlens is between 6.0 microns and 6.2 microns.

APPLICATION

Figure 6. (a) Micrograph array magnified 100 times under the microscope (b) Moire pattern observed under the stereomicroscope (c) Visible dynamic display on the film.

During the checking process, the square-aperture microlens array we fabricated is used in the dynamic display film. The dynamic display film consists of a layer of microlens array and a layer of matching micrograph array. Actually, the dynamic display film is formed by two array patterns Moire. Figure 6 (a) shows the micrograph array magnified 100 times under the microscope. As we can see in Figure 6 (b), microlens array is clear seen as mesh grids, and the image of micrograph array is amplified where the layer of microlens array and the layer of micrograph array are superposed. When we rotate the microlens array, we can see Moire zooming with the revealing layer rotating.

Figure 6 (c) shows the dynamic display we observed directly. We find that the display is moving obviously with the observing angle changing.

The display effects indicate that the square-aperture microlens array we fabricated functions well in dynamic display film, where the precise focal length and high filling factors are required. In order to obtain better image magnification and dynamic display, it is necessary to integrally optimize the structure parameters of the microlens array and the micrograph array in further work.

CONCLUSION

In this paper, the moving mask technology has been introduced as an effective method to fabricate square-aperture microlens array, which comprises two steps: mask
preparation and photolithograph process. And the photolithograph process is carried out in 3 steps: photoresist coating, exposure along X axis and Y axis, and development. By the moving mask technology, the square-aperture microlens array with smooth surfaces and acceptable errors is fabricated successfully, and its filling factor is higher than 95 percent. The microlens array with higher factor means less loss of optical information, which will satisfy higher requirement in optical systems. The result of the application of the microlens arrays in dynamic display film indicates that the microlens array we fabricated has precise focal length and good display effects.

REFERENCES