Design and Fabrication of Variable Focusing Lens Arrays (VFLA) using Liquid Crystal for Integral photography(IP)

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Abstract

In this work, Integral photography with variable focusing lens arrays is proposed. We fabricate two-dimensional liquid crystal lens arrays using cohesion of UV curable polymer and lithography. Applied voltage to the cell alters the effective refractive index of the liquid crystal layer and results in a change of the focal length. By adjusting the focal length, synchronized elemental image array for real or virtual mode is integrated in front of or behind the lens array.

1. Introduction

Investigations of three-dimensional (3-D) display system have been advanced variously for high resolution and a wide-viewing angle. Integral photography (IP), which was first proposed by Lippmann in 1908, is known as one of the most attractive methods for 3-D display because IP provides the autostereoscopic image from a continuous viewpoint and does not require any special glasses. Comparing to stereoscopic method, using binocular parallax, IP has the advantage that wide-viewing angle property is obtained. Recently, it has been studied for 3-D animated images.

In this work, integral photography with variable focusing lens arrays is proposed.

2. Principle of IP using variable focusing lens array

The basic principle of IP using variable focusing lens array is shown in Fig 1.

Generally, the focal length f and the distance d from the lens array to the central depth plane of

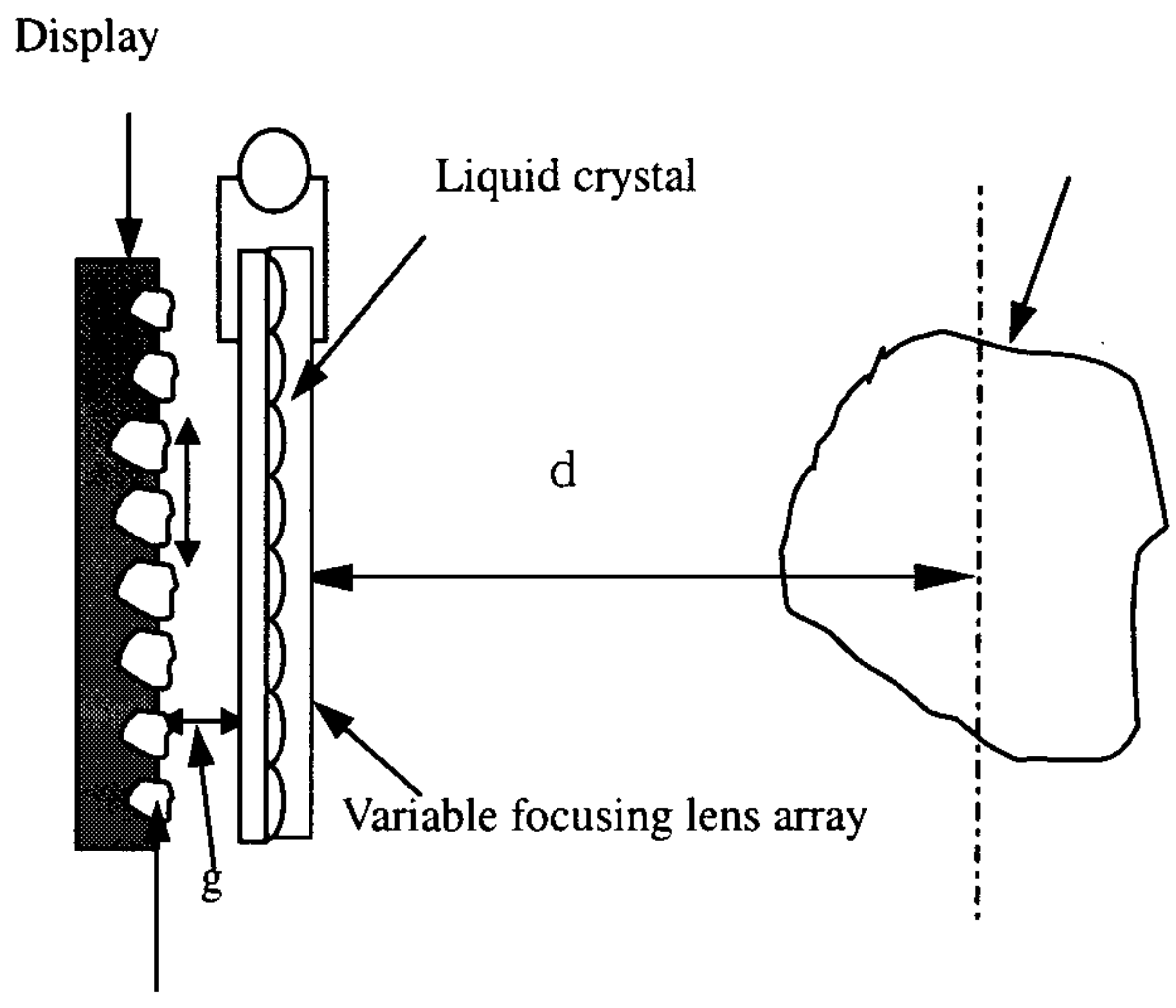


Figure 1. IP configuration with the variable focusing lens array

integral image is expressed as the lens equation:

$$\frac{1}{g}+\frac{1}{d}=\frac{1}{f} \quad ,$$

where g is gap between the display panel and the lens array. Integral images of IP are classified by two modes due to real and imaginary element images. Elemental image for real or virtual mode is integrated in front of or behind the lens array. Because the distances of the real and imaginary integrated image are + d and – d, respectively, we can represent by depth range 2d. If g and f is fixed for these modes, the resolution of integral image is reduced because of the increase of focusing error. By adjusting g [1] or f, we can remove the focusing error. We chose the change of focal lengths in the lens array. The focal length of the variable focusing lens array is represented as follows [2]:

$$f=\frac{1}{(n_l-n_p)C} \quad ,$$

where n_l and n_p are the effective index of liquid crystal and the refractive index of polymer, respectively, and C is curvature of lens. Because applied voltage alters effective index, the focal length is changed.

3. Experiments

We fabricated 4x4 (5x5mm for one lens) and 10x10 (1x1 mm) variable focusing lens arrays. The height of the first lens array and the cell thickness are about 250 um and 450 um, respectively. The polymer NOA 65 (refractive index: 1.524) was used. Liquid crystal ZLI-2395 (E. Merck) with positive dielectric anisotropy was used, and rubbing was done in anti-parallel direction. The second lens was fabricated by lithography. The SEM photographs of the second lens arrays are shown in Fig.2 (a). The photographs of focusing shape in focusing point and out of focusing point of lens array are shown in Fig. 2(b).

The height of the lens and the cell thickness are about 4 um and 8 um, respectively. The width of the lens was determined to minimize the cross-stalk of

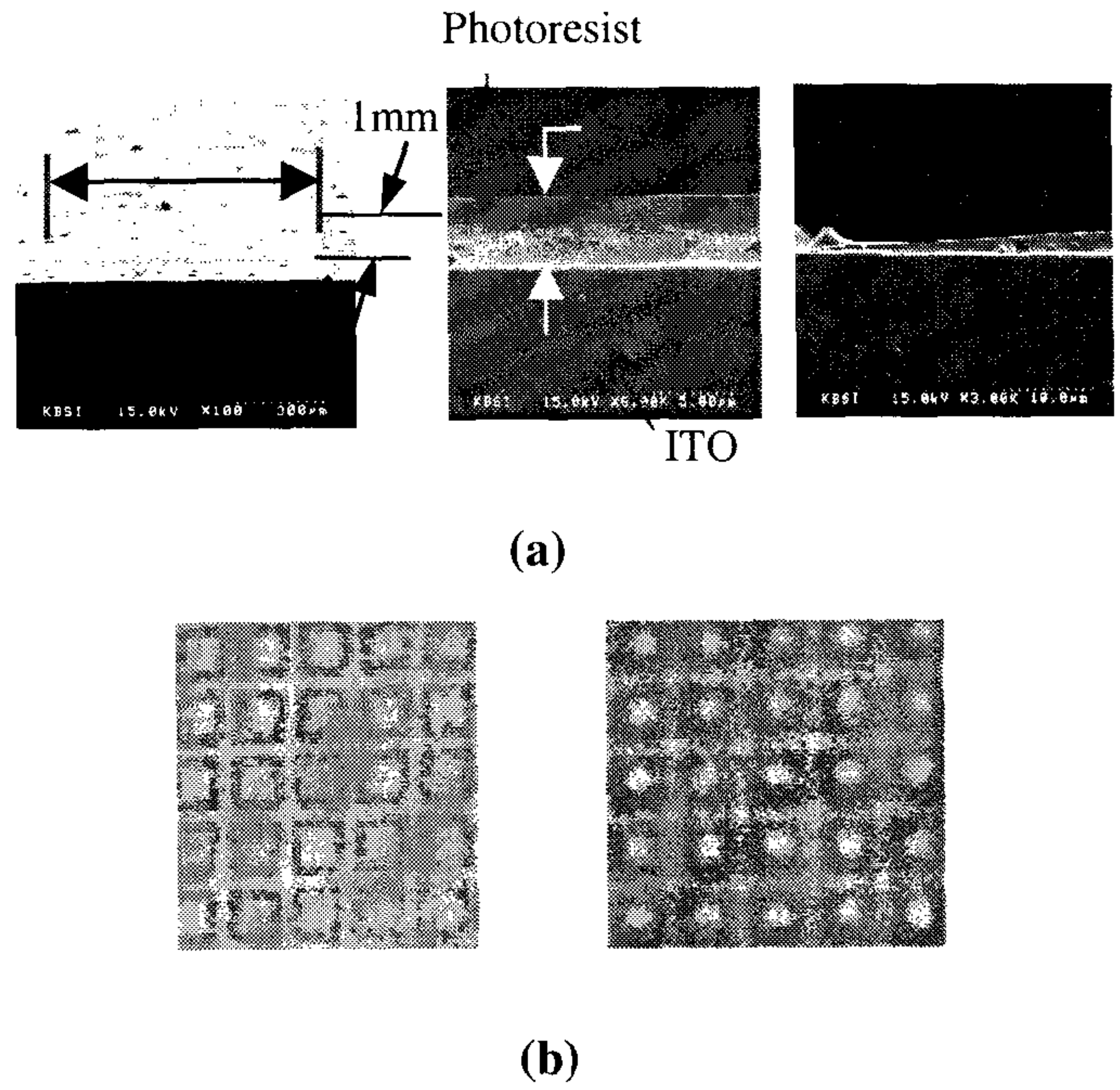
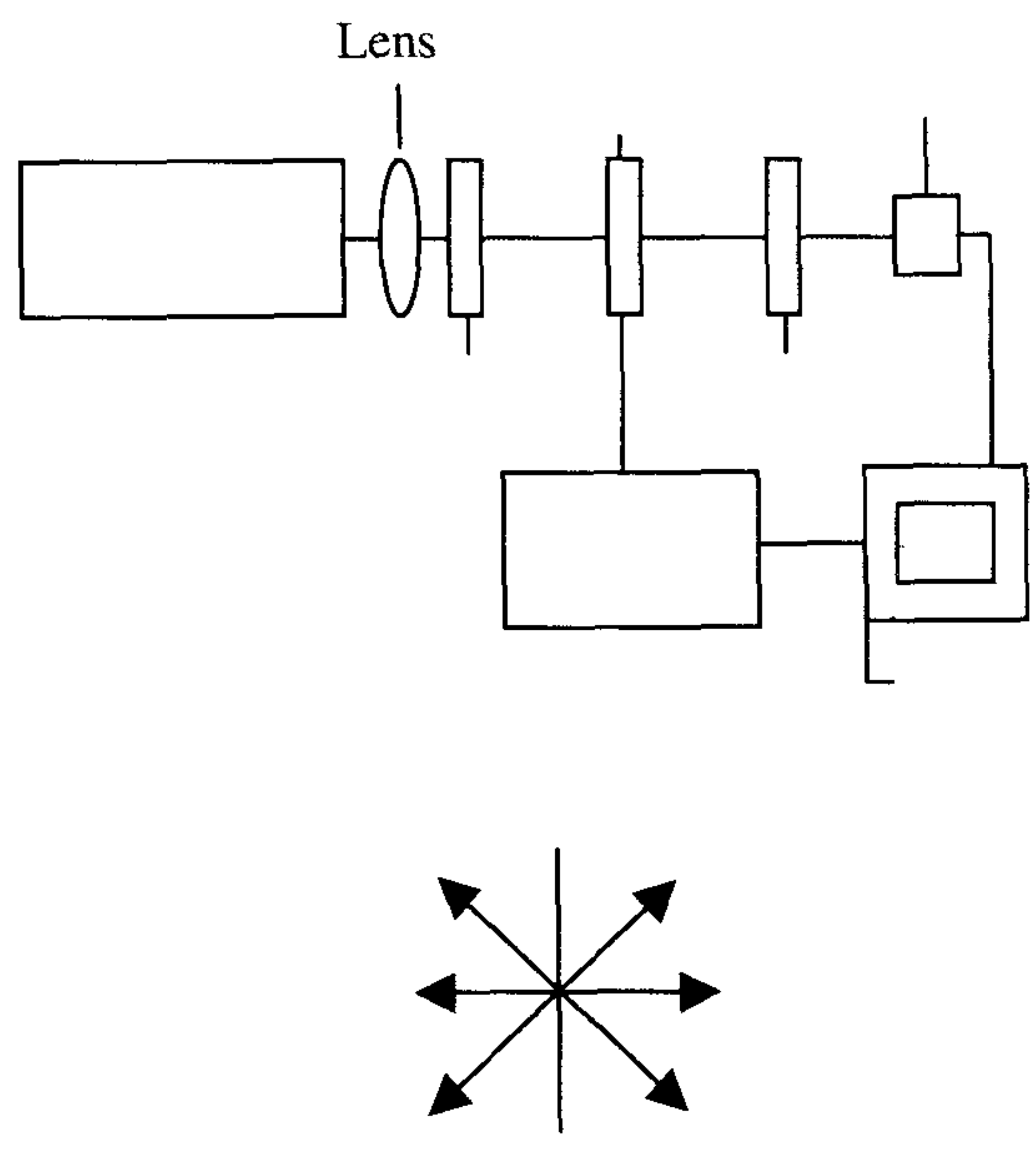


Figure 2. (a) The SEM photographs of the lens (4um on the center) and (b) The photographs of focusing shape in focusing point and out of focusing point of lens array.

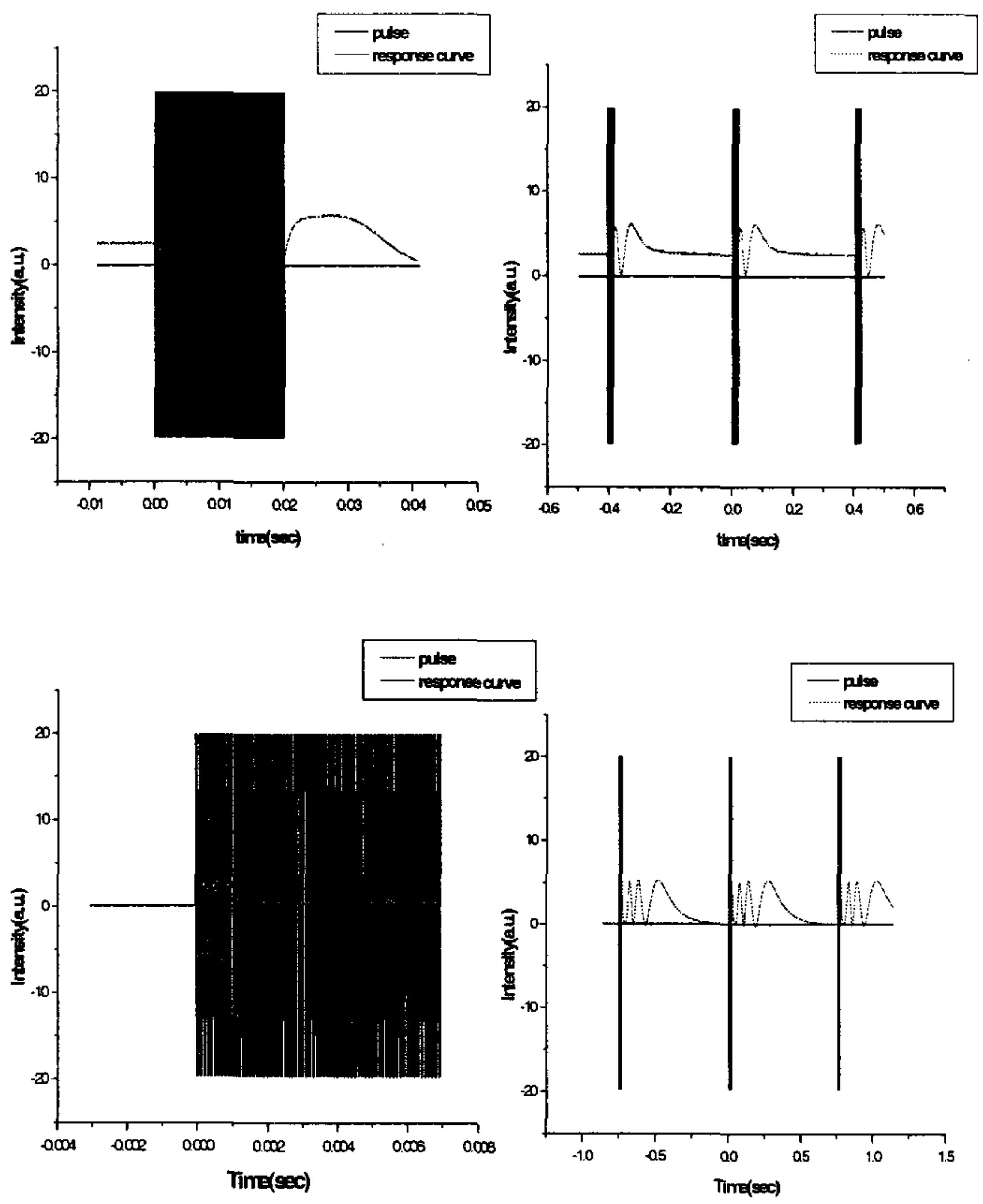


lens [3]. The E7, liquid crystal was used in the second variable focusing lens array. When we measured the focal length, light source Ar^+ laser was used. In order to measure the response time of the fabricated test cell, we set the optical configuration, as shown in Fig. 3.

4. Results and discussion

In the first variable focusing lens array, focal lengths of lens arrays for laser polarization in rubbing direction and in vertical direction are 1300 mm and 200 mm, respectively. For applied voltage 70V, the focal length in the rubbing direction is 200mm.

In the second variable focusing lens array, the focal length was varied from 300 mm to 600 mm. The driving voltage was about 30 V. The rising time was defined to be the time taken for the liquid crystal molecules from homogenous state to homeotropic state. The reverse process was defined to be the falling time. So, the response time is given to the sum of rising and falling time. In the second test cell, those of center and edge of lens are about 200 ms and 500ms, respectively as shown in Fig. 4. In the case of this test cell, we can operate the variable focusing lens array by two frames per second. At this time, Element image and integrated image are shown in figure 5.



(b)

Figure 4. The response time curves of the middle and the edge of lens: (a) middle of lens Rising time 1.5 ms, and falling time 200 ms, (b) Rising time 1.5 ms, and falling time 500 ms

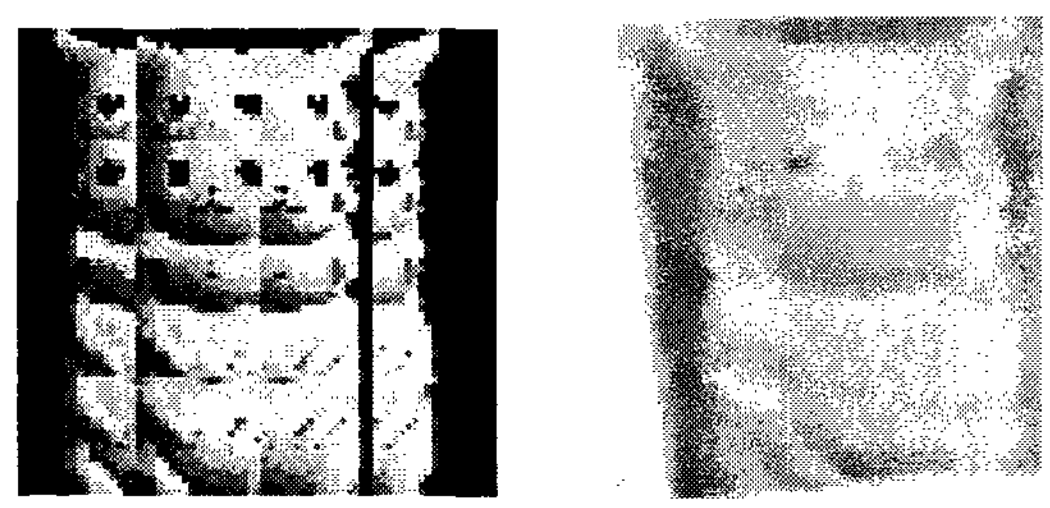


Figure 5. The element image of virtual mode and the integrated image (f: 200 mm)

Integrated image is represented for the vertical rubbing direction and the applied voltage 70 V.

It is identified that by adjusting the focal length, synchronized elemental image array for real or virtual mode can be integrated in front of or behind the lens array. Among the several methods to get 3-D moving picture by IP, A method of the gap control with motor was introduced, recently.

The 3-D display system using the variable focusing lens array is expected to have the simplicity of the configuration, the lightweight, and the mass production. Pseudoscopic image is represented, when the element images obtained by direct pick up is integrated. This IP can show orhtoscopic image instead of pseudoscopic image.

To obtain thin panel, the focal length of lens should be shorter, and the response time is slow still so that it realize moving pictures in real time. To make the shorter focal length, the higher thickness of lens, biconvex structure lens and the higher birefringence liquid crystal material is requested. To satisfy the faster response time, the lower cell gap and the liquid crystal with low viscosity is requested.

5. Conclusion

Integral photography with variable focusing lens arrays is proposed. By fabricating plano-convex variable focusing lens arrays and measuring the electro-optical properties, we explored the possibility of realizing the moving integrated images with large depth and without the decrease of resolution. Variable focusing lens array can be applied for the pickup process to obtain elemental images without decreasing the resolution.

Next, we will represent better results to satisfy these conditions.

6. References

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