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Design and fabrication of square micro-lens array for integral imaging 3D display

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ABSTRACT

Micro-lens array (MLA) with high aspect ratio, precise alignment and great uniformity of focusing are crucial to the integral imaging 3D display systems. In this work, we employed the square micro-lens array (SMLA) with ideal aspect ratio of 100%, to realize high performance integral imaging 3D display systems. The parameters of SMLA and the according reconstruction performances were first simulated using TracePro software, it was shown that the SMLA can effectively reduce the effects of stray light on the reconstruction image, while keeping the brightness due to the high aspect ratio compared to that using circular MLA and pinhole array, thus to achieve high quality reconstruction image. Polymer SMLA with great converging performance and aspect ratio of around 88%, were then successfully fabricated using screen printing technique. An integral imaging 3D display system with high brightness, little color moiré patterns and clear image was demonstrated using the fabricated SMLA, exhibiting good reconstruction performance.

1. Introduction

Three-dimensional (3D) display have been gaining popularity in our daily lives, since it displays more realistically [1–3]. Integral imaging 3D display is one of the most promising naked-eye 3D display technologies, it records 2D projections of a 3D object from many different perspectives using micro-lens array (MLA) and regenerates the rays to produce a 3D object according to the reversibility of optical path. Compared to other 3D display technologies, integral imaging could provide real 3D images with full parallax, continuous viewpoints, full-color; furthermore, it can overcome the viewing fatigue caused by the mismatch of convergence and accommodation [4–6]. Fruitful researches have been conducted using new pick-up and reconstruction methods for the improvements of display performances [7–10].

The MLA is key optical component in the integral imaging 3D display system, and is important in determining the 3D image quality. Although the design and fabrication of MLA have been widely investigated due to its wide applications [11–18], mature fabrication technologies for high quality MLA were considered to be one of the reasons that hindered the further development of prototype and industrialization of integral imaging. The fabrication of MLA with good repeatability of geometry parameters, great uniformity of focusing and good converging performance is still under development for integral Image 3D display. For example, Jung and Jeong [19] have reported a novel method for monolithic fabrication of

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0030-4026/

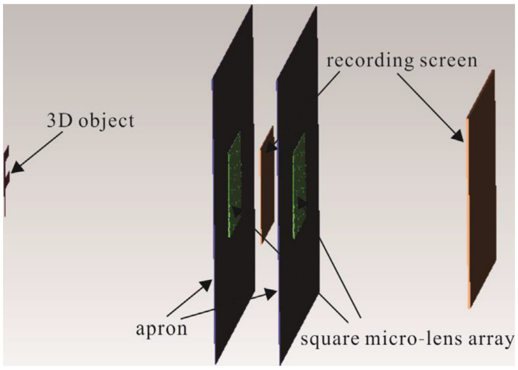

Fig. 1. Schematic integral imaging 3D display system.

Table 1
Parameters of SMLAs and integral imaging system.

Lens and Imaging System	Parameters
Focal Length/mm	24.44
Shape of Lens	Square
Material	PMMA
Object Distance(g)/mm	192.20
Image Distance(g)/mm	27.80
the Radius of Curvature/mm	25.25
Thickness of Lens/mm	0.2

high numerical aperture polymer microlens array with high packing density at assistance of plasma-induced fluorocarbon nanofilm, showing high photon collection efficiency with signal-to-noise ratio greater than 50:1. Wang et al. demonstrated a novel thermal reflow method with an additional near ultraviolet flood exposure and upside-down reflow configuration for the fabrication of MLA with ultrahigh focal number [20].

In our previous study, we have demonstrated a low-cost large-scale fabrication method of micro-lens array (MLA) with precise alignment, great uniformity of focusing and good converging performance using screen printing, and achieved integral imaging 3D display systems with high reconstruction performance. However, it was found that the stray light from the intervals between the elemental micro-lens would induce stray light spots and cause color moiré patterns, leading to the degradation of the image quality [21]. It was also demonstrated that a combined pinholes/microlens array using opaque photoresist to fill the intervals between the elemental micro-lens can reduces remarkably the light spots irrelevanted to the imaging during both pickup and reconstruction of images [9,22]. However, the brightness of the image decreased, as the area of the intervals accounts for around 21% of the total area. Therefore, it is desirable to optimize the MLA structure and develop according fabrication method of large-scale MLA to realize high performance integral imaging 3D display systems. In this paper, we provided a new MLA structure with square elemental micro-lens, which could reduce the effect of stray light to improve the quality of reconstruction images, while keeping their brightness.

2. Simulation and experiments methods

2.1. Design and optimization of square MLA (SMLA)

Integral imaging is based on the reversibility principle of light rays, to reconstruct a 3D scene, elemental images are captured and displayed on a display device and the rays pass through a MLA to reproduce the 3D scene in space. The parameters of 3D display system, such as object distance, image distance, and focal plane of MLA were important for the image quality, thus, TracePro software was used to simulate and determine the parameters of integral imaging 3D display system. Fig. 1 illustrates the schematic integral imaging 3D display system constructed in TracePro software, the according parameters are shown in Table 1. The 3D object is designed as the “F” letter, and the surface facing to the SMLA is set as the surface light source. The recording screen is set as “light all through” when recording process is analyzed, which could record the information of the three-dimensional object well. The reconstruction screen is set as “absorb light completely” when reconstruction process is analyzed, that is, the information obtained during the recording process is sent to the reconstruction process, the effect of integral imaging can be quantified by observing the illumination map of the reconstruction screen. In order to compare the effects of SMLA on the quality of reconstructed image, integral imaging systems using traditional micro-lens array and pinhole arrays are also established, with the other parameters identical. The creation process of SMLA is explicated in Fig. 2. Firstly, a circular micro-lens and a cuboid with square bottom and with the same thickness are created and put together, the diameter of the circular micro-lens is equal to the diagonal line of the bottom square surface of the