LC Lens Fabricated by Photoalignment for AR/VR Systems

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ABSTRACT

A concept for an electrically tunable liquid crystal (LC) lens using a hole-patterned electrode and the vertical alignment liquid crystal cell by circular photoalignment is demonstrated. The proposed LC lens is a polarizer-free negative lens (0D ~ -0.93D) by changing the driving voltage. The proposed LC lens can be applied for AR/VR applications.

1. INTRODUCTION

The liquid crystal (LC) lens has focal length tunable electrically. Comparing with the zoom function of a conventional zoom lens system realized by mechanically moving the inner individual elements, the LC lens is more compact and lightweight. Various lens structures have been proposed, such as three electrodes with two-voltage-driving to control focal length from negative to positive [1] and coating high resistance layer yielding lower driving voltages [2]. The focal length of LC lens is controlled by changing the phase retardation [3].

One of the main disadvantages of LC lens is the polarization dependence and aberration from the non-symmetry structures between electric filed and LC alignment direction. Using polarizers in LC lens system drastically reduces the light amount passing through the optical systems [4]. There are many approaches to obtain polarizer-free LC lens, such as fabricating LC lens with blue phase LC [5] and stacking two LC lenses with orthogonal rubbing directions [6-7].

This work presents a negative LC lens using the photoalignment method with a simple hole-patterned electrode [8]. The LC directors are aligned with a circular symmetry and the polarization-free lens is obtained. We apply our LC lens on AR display to solve the mismatch of reality object and virtual image position. The mismatch might induce visual fatigue while continuously adjusting the LC lens in order to focus on reality object and virtual image. To overcome these problems, a set of tunable LC lens is proposed in this work.

2. EXPERIMENT

We have demonstrated an electrically focusing LC lens with the commercial UV^{2}A photoalignment polyimide (PI) and a hole-patterned electrode as shown in Fig. 1. A LC layer of 50 μm is sandwiched between two glass substrates. The surface facing the LC layer of the lower substrate is coated with an indium tin oxide (ITO) film as one transparent electrode. Another surface, not facing the LC layer of the upper substrate is coated with an aluminum (Al) film acting as another electrode, and there is a hole of 7 mm diameter in the center as shown in Table 1.

We spin-coated the surfaces of the substrates with photo-crosslinking PI which facing the LC layer, the photo-crosslinking PI was developed for an alignment layer of liquid crystal display panels. Then the substrates was hard baked at 200°C for forty minutes to form the alignment films. Fig. 2 shows an experimental arrangement for irradiation of linear polarization ultraviolet (UV) light source. A linear polarization UV light source is generated by EXECURE 4000 (HOYA Co., Ltd.) with a Glan Taylor polarizing prism. The linear polarization UV light source, propagating along the x-axis with an angle about 30-50 degree. It then passed through the Glan Taylor polarizing prism, and irradiated onto the PI films. The sample was attached to a rotating platform. The illumination duration was ~10 sec. Change the direction of linear polarization UV light source, a symmetrically radial LC alignment is formed.

We exposed the photo-cross-linkable PI to 60 mW linearly polarized UV light, and assembled a cell with both top and bottom substrate made of this UV-exposed PI-coated substrate. The spacing between the two substrates was 50μm. After assembly, the cell was filled with negative dielectric anisotropy (Δn=0.096, $\Delta \varepsilon$ = -2.8) liquid crystals at room temperature in the nematic phase.

The most important distinctive feature of our approach is that the nematic LC directors aligned symmetrically when applied voltage. The LC film viewed from the top is illustrated in Fig. 3.

When applying the driving voltage, the LCs tend to be aligned normal to an electric field. Thus, the proposed LC lens functions as a negative lens due to a concave phase profile caused by the inhomogeneous electric field inside the LC cell, as shown in Fig.4.

The LC lens can be applied for AR/VR applications. Table 2 shows the specification of our adjustable focal plane AR display design and the layout is shown in Fig. 5. We also apply our LC lens on AR display to solve the mismatch of reality object and virtual image position might induce visual fatigue while continuously adjusting the LC lens in order to focus on reality object and virtual image. The proposed AR system included an OLED display, a beam splitter (BS), an LC lens, and a concave mirror. When the light emitted from the OLED display traverses the BS, LC lens, and concave mirror, the image in the OLED display is reflected by the BS into an observer's line of sight. The observer can see this light and also the light or images originating from the surroundings.

3. RESULTS

To confirm the circular symmetric properties of the LC orientation, we set a polarizer in front of the LC lens, the polarizer was rotated through 0 ~ 90° while the LC lens was held stationary. As shown in Fig. 6, the results demonstrate that the black pattern changed symmetrically. This observation confirms that the LC directors are indeed circular symmetry.

The negative lens diverges incident light beam. The spot of an incident random polarization He–Ne laser beam in a plane approximate 1m behind the LC cell is shown in Fig. 7. Fig. 7(a) shows the spot when the LC lens without driving voltage. The spot size equals approximately the lens size, ~ 9 mm. When the voltage is applied, the LC cell works as a negative lens. The incident light beam is diverged and the beam spot is greatly enlarged, as shown in Fig. 7(b)

Fig. 8 present the images of a symmetric radial LC lens under the crossed polarizers. To confirm our LC lens is polarization independent, the LC lens was rotated 90° under the crossed polarizers. The results demonstrate that the interference ring remains unchanged. The image is independent of the polarization. When rotating the LC lens under the crossed polarizers, the crossed dark lines are rotated showing the circular symmetry property.

4. CONCLUSION

In this letter, we design a UV²A LC lens with hole-patterned electrode and the focal length can be adjusted by applying different driving voltage. The power of the UV²A LC lens can be controlled from 0D ~ -0.93D. The lens structure is very simple and the result shows the LC lens can be operated without polarizer. The proposed LC lens is applied for adjustable focal plane VR display. A compact size with less components is also shown in our design. Without using polarizers we achieved a high efficiency system.

Table 1 Parameters for PSVAs nematic LC lens.

Item	Parameters
Thickness of glass substrate	1mm
Cell gap	50μm
Circular hole electrode diameter	7mm
LC layer	UV²A vertical alignment liquid crystals

Table 2 Specifications for the Adjustable Focal Plane AR system

Item	Parameters
Exit Pupil Diameter	3 (mm)
Eye Relief	10(mm)
FOV	21.72° (diagonal)
Design Wavelength	486, 587, 656 (nm)

Table 3 Specification for OLED micro-display panel

Panel Type	OLED
Display Size	0.294"
viewing angle	21.33° (diagonal)

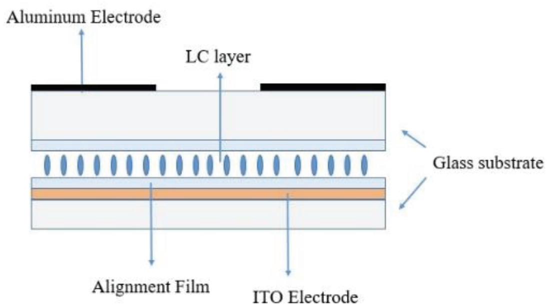

Fig. 1 Structure of UV²A nematic LC lens.

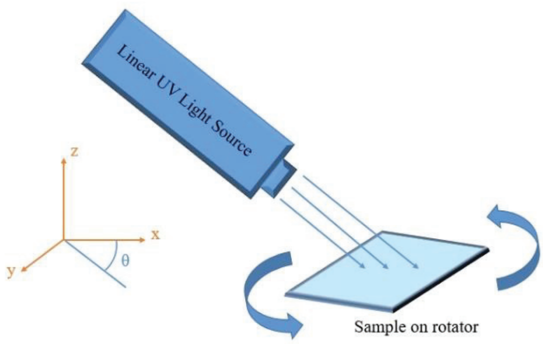

Fig. 2 Fabrication set up

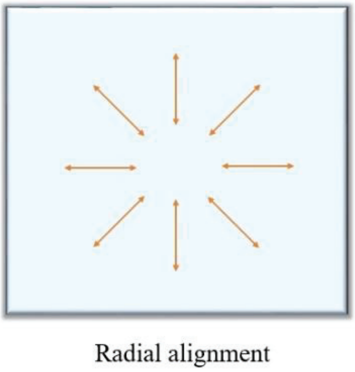

Fig. 3 Top view of LC films

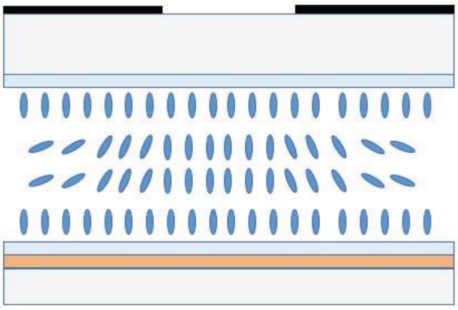

Fig. 4 Design of the UV^2A negative LC lens

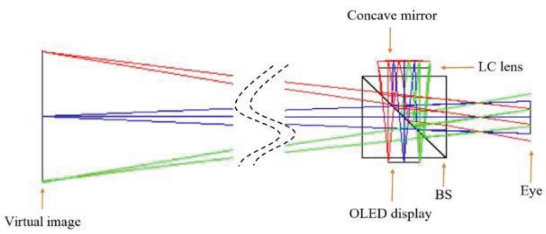

Fig.5 Optical system for augmented reality

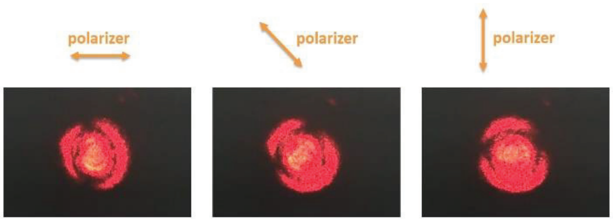

Fig. 6 LC directors are indeed symmetric.

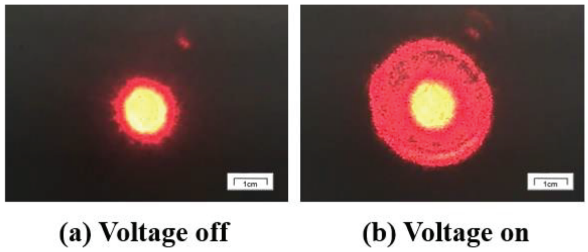

Fig. 7 Collimated light without polarized passed through the LC lens

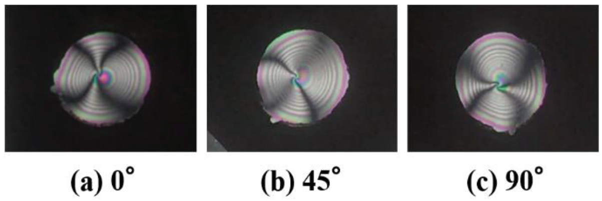

Fig. 8 Rotated the LC lens under the crossed polarizers

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