Adaptive Liquid Crystal Lens(LC-Lens) Array for 3D Display and Capturing

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Abstract: A low driving voltage with fast response LC-lens was developed. By implementing the LC-lens as an array structure, it can be adaptively used for 2D/3D switching and 3D rotation on autostereoscopic display. Additionally, it also can be utilized as a depth sensor for 3D capturing.

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1. Introduction

Liquid crystal(LC) lens[1,2] is a single tunable lens which is electrically controllable focal-length without any mechanical movement. The major technical challenge of LC lens is to create a smooth gradient refractive index distribution [3]. Homogeneous and in-homogeneous LC-lens, as shown in Fig. 1(a) and (b), can generate a great index distribution by fabricated lens profile in the LC cell. However, the complex structure becomes an issue for practical application. Fringing-field Controlled LC lens(Fig.1 (c))was proposed with a very simple structure, yet it need a very thick dielectric layer, such as glass, to smooth the fringing-field from edge to central of the lens. This thick dielectric layer will results in high driving voltage (>50Vrms) and slow response time (>10sec). Therefore, we proposed a "Gradient-driven Liquid Crystal lens (GDLC-lens)" to yield low driving voltage and fast response time. By achieving the two properties, GDLC-lens can be extended for array system on 3D display and depth sensing applications.

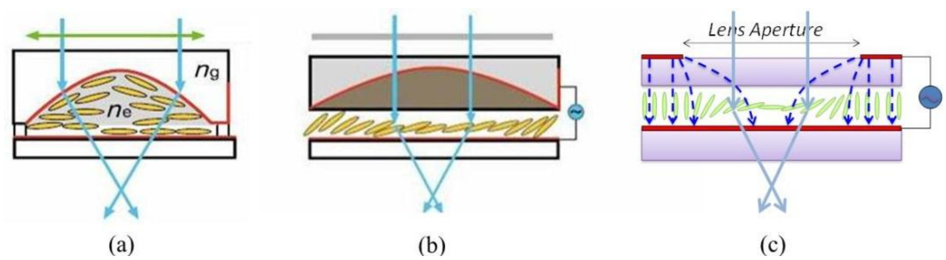


Fig. 1. Three main types of LC-lens, (a) In-homogeneous, (b) Homogeneous, (c) Fringing-field Controlled.

2. Gradient Driven LC-lens (GDLC-lens)

For fringing-field controlled LC-lens, if without using thick dielectric layer, which means the driving electrodes were built inside of the LC cell, the electrical field will not be smoothly distributed, as shown in Fig. 2(a). Therefore, once it has an electrode can have gradient voltage distribution(Fig. 2(b)), an ideal electrical field profile can be easily generated. To realize the gradient driving electrode, we proposed to use a high-resistance layer, which was spin-coated on patterned electrodes. The electrodes were inside glass substrate and contact LC molecules directly, therefore, the internal electrodes surface can preserve most of the applied energy to much lower the driving voltage with fast response time. Additionally, by operating different voltages on the patterned electrodes, convex and concave LC lens modes can be generated.

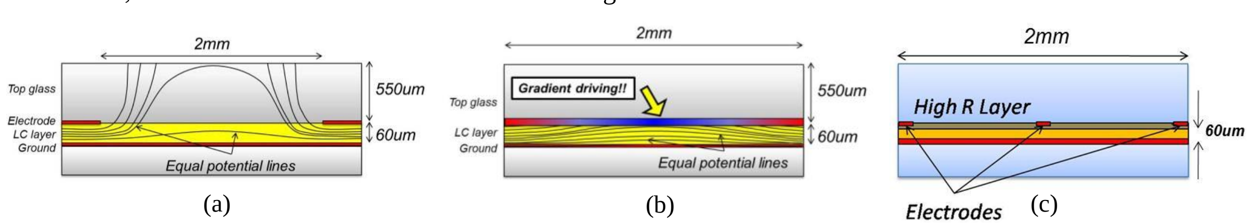
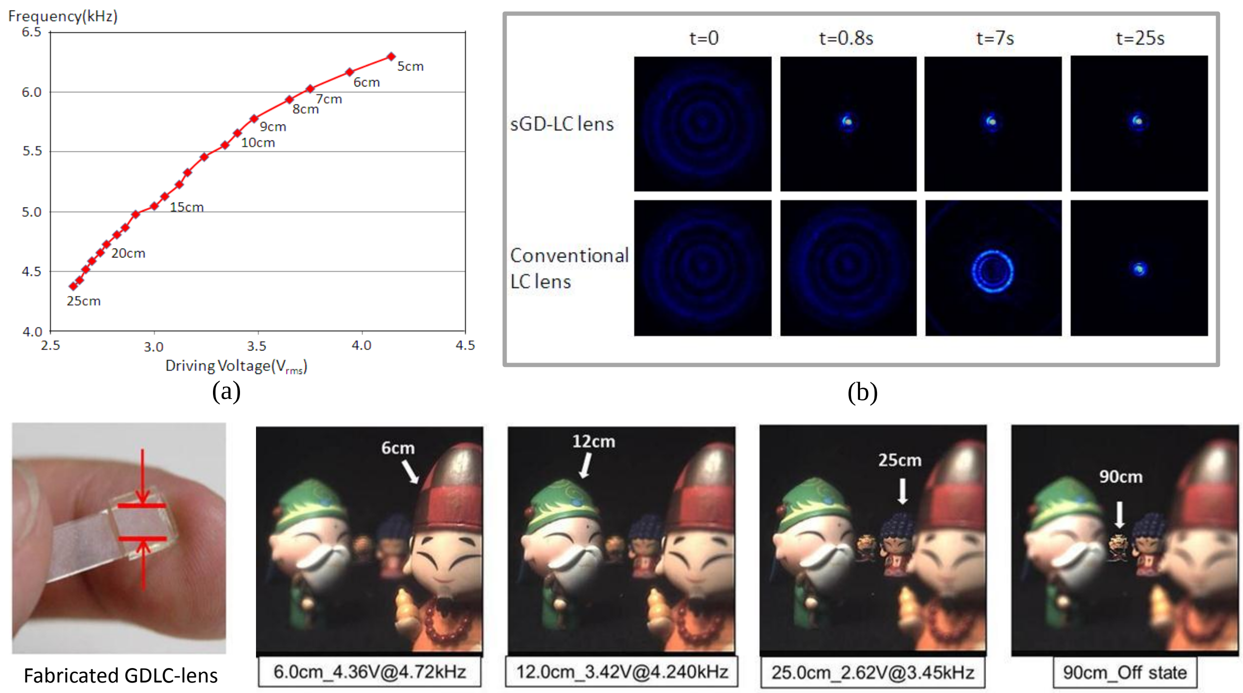


Fig. 2. (a) In-cell electrode without thick dielectric layer, (b) In-cell electrode with gradient voltage distribution, and (c) proposed GDLC-lens structure: Coated high resistance layer with In-cell electrode to generate gradient voltage distribution.

The experiment results of focal lengths and its controlling voltage-frequency are illustrated in Fig. 3(a). The driving voltage was significantly reduced to less than $5V_{rms}$ for 5cm focal length within the driving frequency of 4kHz ~ 6.5kHz. Regarding to the focusing speed /Response time(Fig.3 (b)), the result shows an fast focusing of GDLC-lens within 0.8 sec by 3.75Vrms stable operating voltage. Compare to that of conventional fringing-field controlled LC lens, which has 25sec response time with 25Vrms operation, this results showed a dramatic improvement. The photos of different focusing which was taken with GDLC-lens are shown in Fig. 3(c). Obviously, the GDLC-lens can easily optimize the adaptive the focal length with low driving voltage. Furthermore, the fast auto focusing function of GDLC-lens is on: http://www.youtube.com/watch?v=XxjK6Vae5eM&feature=youtu.be.

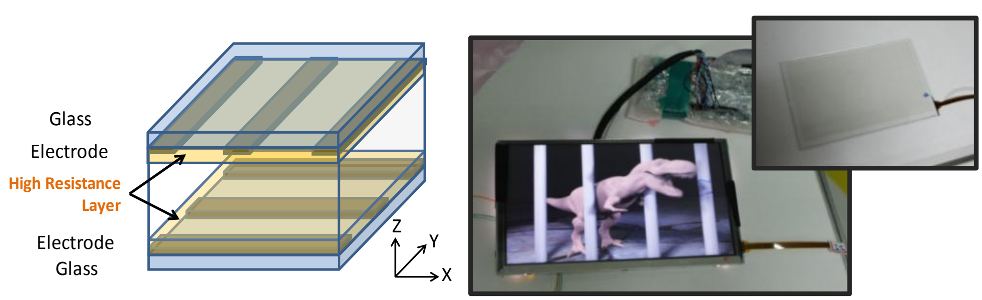


(c)

Fig. 3. Experiment results of (a) Focal length with driving voltage, (b) Focusing time of GDLC-lens and conventional LC-lens, and (c) Auto focusing images with various distance objects.

3. Lenticular GDLC-lens Array for 3D Display

By designing the lens as lenticular array shape, GDLC-lens can be used for not only 2D/3D switch[4], but also 3D rotation. The structure of rotatable GDLC-lens is shown in Fig. 4(a). In order to show 3D image in orthogonal direction, the pattern electrode and high resistance layer is fabricated in both of the top and bottom glass. The patterned electrodes, of course, should be perpendicular to each other. If GDLC-lens, for example, is rotate to horizontal direction, the top electrode is connected to ground, and only drives on bottom electrodes.



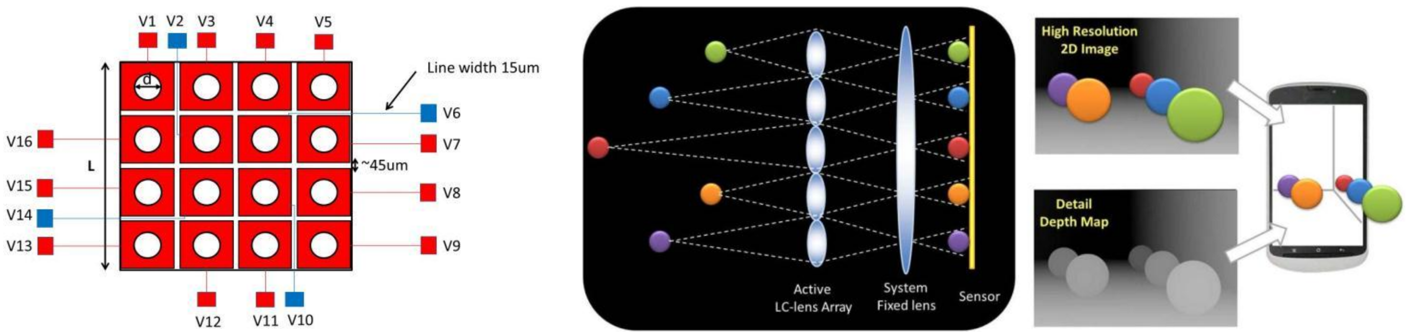
(a) (b)

Fig. 4. (a) The electrode structure of rotatable GDLC-lens, and (b) the fabricated 7-inch GDLC-lens array panel for 3D display.

A 7-inch 2D/3D switchable and 3D rotatable auto-stereoscopic display by lenticular using GDLC-lens array is shown in Fig.4 (b). For this demo panel, the driving voltage is less than 5 voltages, the switching time is less than 1sec, and the crosstalk was 25% at ideal viewing distance. Although the crosstalk of GDLC-lens array still has space to be improved, yet the results had successfully demonstrated the practical application potential of it.

4. Circular GDLC-lens Array for Depth Sensing

To further apply the GDLC-lens on 3D sensing, it can be designed as adaptive circular lens array, as illustrated in Fig. 5(a). Every single lens can be controlled individually to adjust its focal length. Therefore, the proposed structure can easily sense the 3D depth without any mechanical moving, but just changing the focal length of each lens electrically. Comparing the axially distributed image sensing, light-field, and integral-photo technologies[5-7], GDLC-lens array capturing can sense the 3D depth just in single shot (1 step) with less computing process. Additionally, the lens array also can be switched on and off, thus the high resolution 2D image and 3D depth map can be captured (Fig. 5(b)). Finally, our proposed lens array can provide full resolution 2D image with high accurate 3D depth to generate a high quality 3D image.



(a) (b)

Fig. 5. (a) Proposed circular GDLC-lens array for 3D sensing. (b) By adaptively changing the focal length of each lens, it can easily captured a high resolution 2D image and 3D depth map to generate a high quality 3D image.

5. Conclusions

Gradient-Driven Liquid Crystal lens (GDLC-lens) was proposed to yield low operating voltage with fast focusing. The focal length was tunable from infinity to 5cm with only less than 4Vrms driving. The focusing time was dramatically improved to 0.8sec. Compare to the conventional result, which the regular focusing time is >25sec and requires extremely high driving voltages, GDLC-lens brought the applications utilizing LC lenses to be feasible and practical. To further implement the GDLC-lens as lenticular lens array on a 7-inch display, we successfully demonstrated its 2D/3D switching and 3D ratable function. Additionally, by extending a single circular lens as individually controlled lens array, GDLC-lens array can capture full resolution 2D image with high accurate 3D depth. Consequently, the adaptive C-lens array really shows the potential on 3D related applications.

6. References

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