25.1 *Invited Paper:* High resolution Autostereoscopic 3D Display with Scanning Multi-Electrode Driving Liquid Crystal (MeD-LC) Lens

***Yi-Pai Huang*[2*], *Chih-Wei Chen*[1], *and To-Chiang Shen*[1]**

Department of Photonics & Institute of Electro-Optical Engineering[1], Display Institute[2]

National Chiao Tung University, Hsinchu, Taiwan, 30010

Abstract

An *autostereoscopic display with full resolution of 2D and 3D images with wide viewing angle potential was proposed by combining an "active scanning film" and fast response OLED. In order to realize the active scanning film to project the images to different directions sequentially, Multi-Electrode Driving Liquid Crystal (MeD-LC) Lens was utilized. Comparing with traditional LC lens structures, MeD-LC lens could not only be switched on/off, but also horizontally moved to "scan" and project images. Additionally, MeD-LC lens was more competitive in respect of structure simplicity and various curvature generations.*

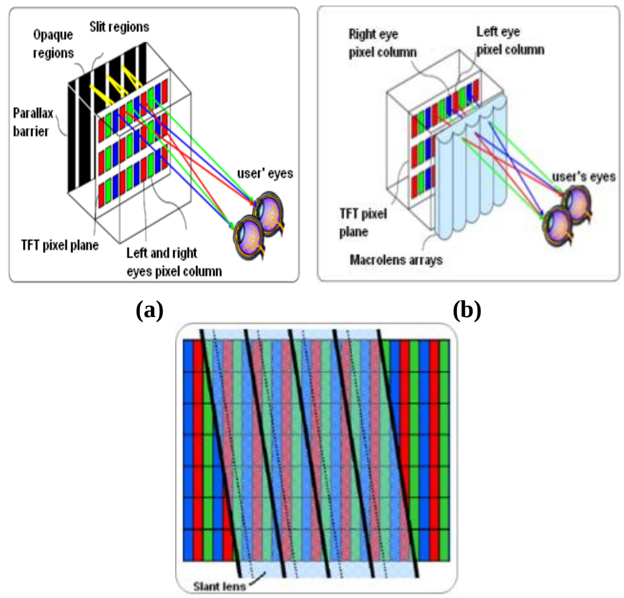
1. Introduction

Developments of display were driven by trying to realize the natural view. Especially the 3D display had caught much interest for all of us. Now, some 3D mode displays had the opportunity to switch between 2D and 3D mode [1][2] such that either natural 3D images or high resolution 2D could attract more attention in consumer marketplace. Although the stereoscopic 3D displays had come for a long way, some prior arts such as parallax barrier [3] and cylindrical lens arrays [4] in Figure 1(a) and (b) were proposed but existed some issues of narrow viewing angle and low resolution. Besides, the former caused low brightness because the light was absorbed by barrier patterns. Therefore, the wide viewing angle approach of the current 3D display with slanted lens [5][6] in Figure 1(c) was proposed which could be obtained although it was also suffered issues of lower resolution since the pixels were divided for more views and still limited the views and that became a trade-off with resolution. Therefore, new displays with full resolution 2D and 3D stereo, freedom of movement, and multi-user potential became important for realizing the natural view.

Currently, the pixel resolution (x, y domain) was sacrificed for yielding more views. Therefore, we proposed an "active scanning film" to integrate "time(t)" domain to "scan" the images with high frame rate. The active scanning device could compensate the resolution with viewing angle efficiently. However, this high frame rate device should have fast response time to display various image sequentially. Consequently, an OLED display with microsecond switching time will be utilized. The final schematic plot was shown in Figure 2. As a result, a compact form of flat panel could yield a 3D image in full view without degrading the image resolution could be realized.

2. Active Scanning Film

The active scanning film made by liquid crystal lens was utilized for active scanning film. Conventional cylindrical LC lens [7] structure had two parallel electrodes as shown in Figure 3(a), the rubbing direction of LC layer was parallel to the slit, d was the cell gap as well as W_L was the unit lens width. Moreover, W_E and



(a) (b)

(c)

Figure 1. Structure of current 3D displays (a) parallax barrier (b) lensticular lens array, and (c) Slant lensticular lens array.

Ws were electrode width and slit width respectively. After applying the operated voltage V, the form in LC layers spatially nonuniform and the electric field was axially symmetrical that reoriented the LC director as shown in Figure 3(b).

Furthermore, the refractive index difference (Δn) in Eq. (1) between the center and the edge could be evaluated by transposing the Fresnel's approximation [8].

$$\Delta n = \frac{r^2}{2df} = \alpha \cdot r^2 \qquad (1)$$

The Δn was a function of parabolic curve with a constant α, where α was equal to 1/ (2df). Hence if the curve of Δn was closer to the ideal parabolic curve, the LC lens could get more specific focal length. However, the double-electrode structure had a big issue of low effective aperture width due to the slit was so wide in comparison with the lens in small voltage that electric field could not affect the LC near the center; in large voltage, the changing of electric field between electrodes were too severe thus making the profile became disorderly, which simulation results was shown in Figure 3(c). The device was filled with the nematic liquid crystal E7 (Δn = 0.22).

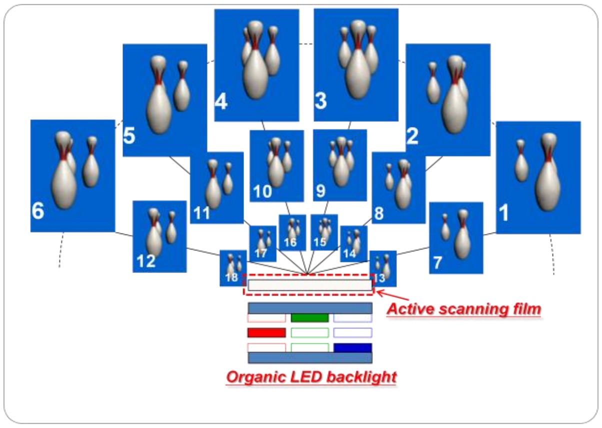
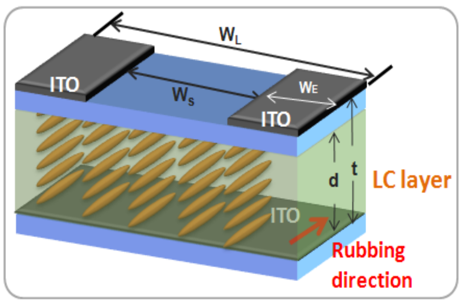
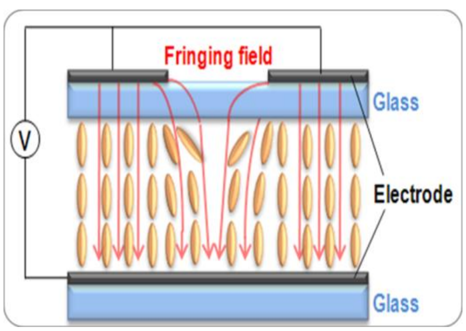


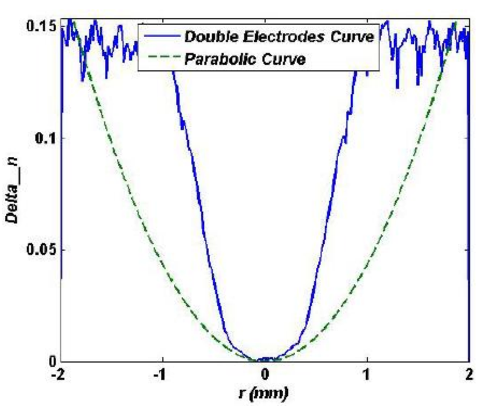
Figure 2. Scanning 3D system with "active scanning film" + "fast response OLED".



(a)



(b)



(c)

Figure 3. Structure of the traditional LC lenticular lens (a) Top view, (b) Side view, and (c) simulation of Δn curve.

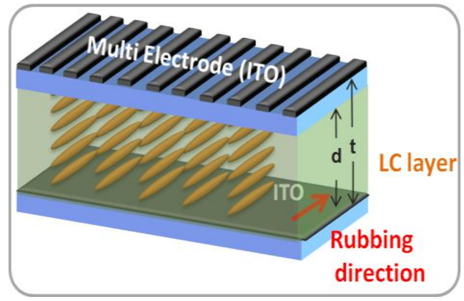


Figure 4. MeD-LC structure

In order to solve the non-ideal lens curvature and for sequentially moving the lens, a novel structure "Multi-Electrode Driving Liquid Crystal (MeD-LC) lens" was proposed, as illustrated in Figure 4. By applying the operating voltage sequentially, the LC layer in MeDLC device will reorient and build in a lens-like shape, thus the lens could move(shift) on the horizontal direction to project the images to different viewing angle without degrading the resolution as shown in Figure 5.

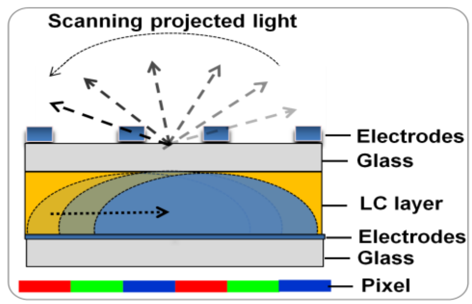


Figure 5. Scanning MeD-LC Film.

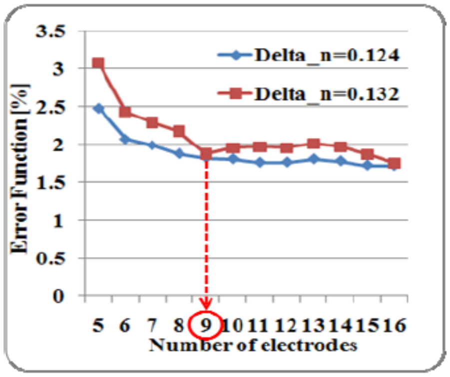
3. Simulation and Experiment

For simulating the refractive index difference (Δn) of MeD-LC device as shown in Figure 4, the ratio of W_L/t (cell thickness t) were chosen as an optimum value which is about 2-3, where the effective area with the parabolic refractive index distribution became maximum [9]. Here we used a 300μm glass (ε=6.9) and lens width W_L = 740μm. Additionally, in order to judge the difference between the ideal curve and simulation curve, we defined an error function (EF) as shown in Eq. (2).

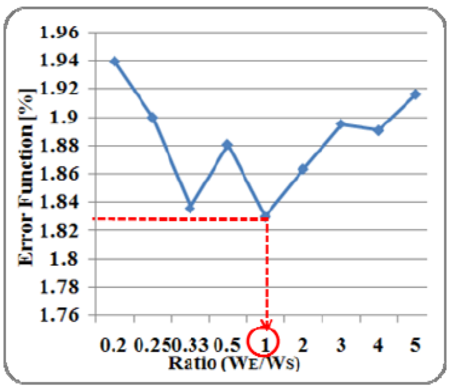
$$\mathbf{EF} = \sqrt{\frac{\sum_{i=0}^{aperture\ Size}(S_i - P_i)^2}{aperture\ size}} \times 100\% \qquad (2)$$

In order to keep the parabolic profile and large Δn, optimizing number of electrode and the ratio of W_E/W_S was needed because that could affect the profile much. From the simulation shown in Figure 6(a), when the number of electrode was over 9, the changes of EF became saturate. Additionally, under 9 electrodes, the ratio of W_E/W_S=1 had the lowest EF shown in Figure 6(b). Finally, the simulation result of Δn curve for 9 electrodes with the ratio of W_E/W_S=1 was shown in Figure 7, which demonstrated an ideal parabolic curvature.

The scanning MeD-LC lens with optimized structure had been fabricated. The experimental measurement setup and the fabricated MeD-LC device were shown in Figure. 8 and Figure 9. The film was formed by four groups of MeD-LC devices which cell gap and aperture size are about 60μm and 1.5mm.

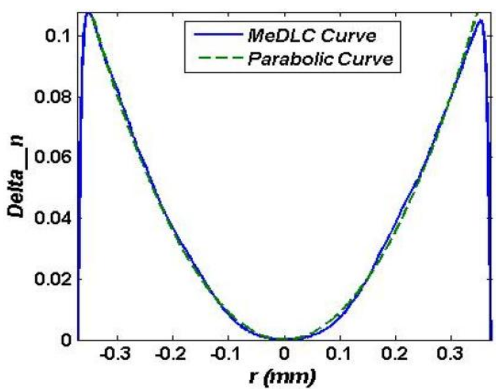


(a)



(b)

Figure 6. Simulation result of (a) error function (EF) vs. number of electrodes, and (b) EF vs. ratio of W_E/W_S.



(c)

Figure 7. Simulation result of ∆n curve for optimized multi-electrode structure.

For measuring the scanning film, the MeD-LC device was driven by different voltage at each individual electrode with frequency about 1 kHz, and the direction of polarizer was parallel to the electrode. The captured focused intensity image and the crossed intensity profile along AA' were shown in Figure 10(a) and (b). According to Figure 10(b), the green line and red line represented the MeD-LC lens which was driven and undriven respectively. The results showed that MeD-LC lens could focus the light effectively at the center of the lens aperture which the focal length was about 4.6cm. It also conformed to the simulation result which the focal length was about 4.3cm.

Figure 8. The experiment setup.

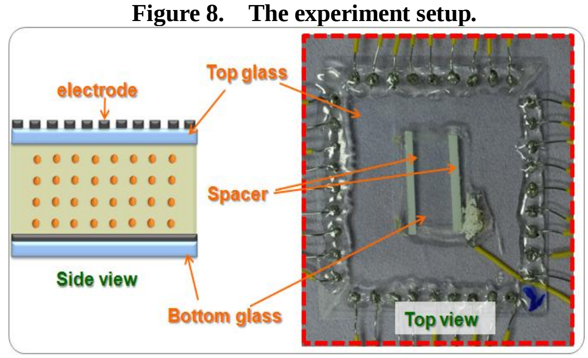
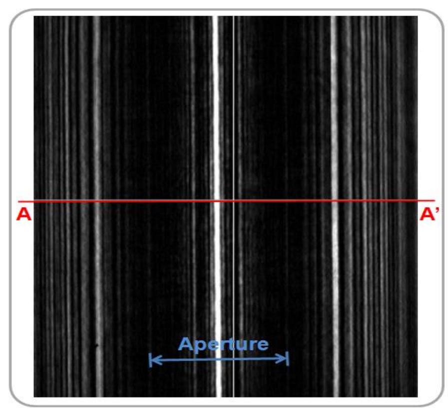
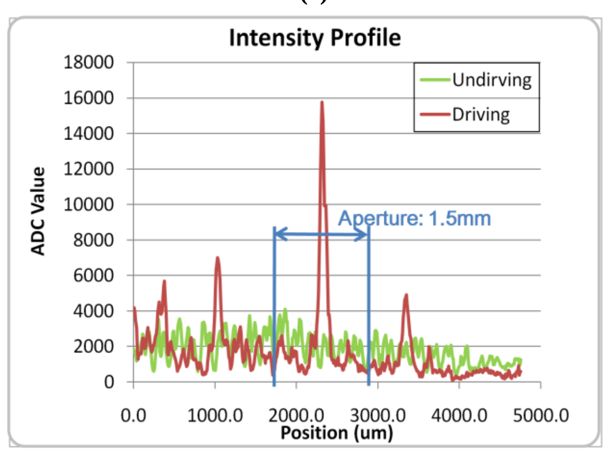


Figure 9. The MeD-LC device.



(a)



(b)

Figure 10. (a) The focused intensity image and (b) intensity profile along AA'.

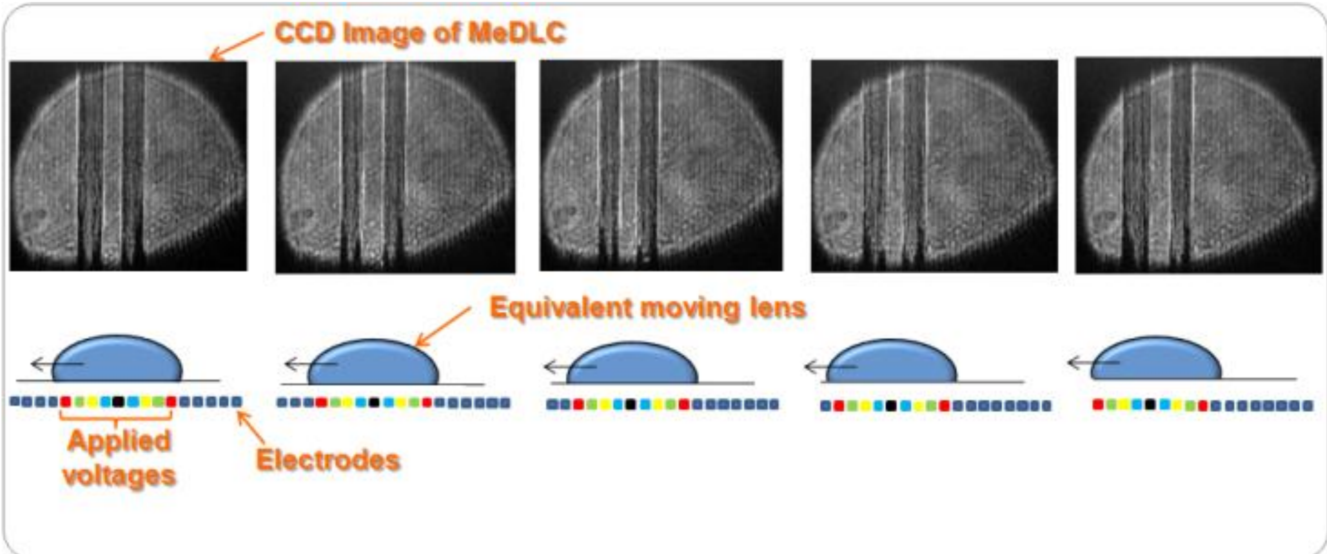


Figure 11. The capture images of "scanning" MeD-LC lens.

The captured image with scanning MeD-LC lens moving back and forth was demonstrated when turning on the voltage sequentially, as shown in Figure 11. The dynamic moving video of MeD-LC lens could be seen from the link: http://adolab.ieo.nctu.edu.tw/albums/pic.php?CID=2&Album_ID=11&Photo_ID=228 .

4. Conclusion

We proposed an approach that combined active scanning film (temporal domain) with fast response emissive OLEDs to scan the projection directions with high frame rate images, yielding super-wide-viewing 3D images with high-definition quality. A Multi-Electrode Driving Liquid Crystal (MeD-LC) lens with optimized electrode number (9-electrodes) and W_E/Ws ratio was demonstrated. The MeD-LC lens was successfully scanned in horizontal direction by applying the voltages sequentially on the multi-electrodes. Consequently, this scanning MeD-LC lens could be utilized for time domain resolution to compensate the viewing angle issue of auto-stereoscopic 3D display.

5. Acknowledgement

This work was financially supported by National Science Concil, Taiwan, under contrasts NSC 97-2220-E-009-030.

.

6. References

[1]Hyung-ki Hong, Sung-min Jung, et al, "Autostereoscopic 2D/3D Switching Display Using Electric-Field-Driven LC Lens(ELC Lens)," SID Symposium Digest, pp348-351, 2008.

[2] G.J. Woodgate, J. Harrold, "High Efficiency Reconfigurable 2D/3D Autostereoscopic Display," SID Symposium Digest, Vol. 34, pp.394-397, 2003.

[3] H. Isono et al. Japanese Pat. Appln.JP03-119889, (1991)

[4] Hongwen REN, Yun-Hsing FAN, et al. "Tunable-Focus Cylindrical Liquid Crystal Lens," Jpn. J. Appl. Phys. Vol. 43, pp.652-653 (2004).

[5] C.V. Berkel et Al, "Characterization and optimization of 3D-LCD module design," SPIE. vol. 3012, pp.179-187 (1997)

[6]Jung-Young and Bahram Javidi, "Three-Dimensional Image Methods Based on Multiview Images," J. Display. Tech., Vol. 1, pp. 125-140, 2005.

[7]Yi-Hsin LIN, et el, "Tunable-Focus Cylindrical Liquid Crystal Lenses," Jpn. J. Appl. Phys. Vol. 44, No. 1,pp. 243-244,(2005).

[8] J.W. Goodman, Introduction to Fourier Optics, McGraw-Hill, New York, 1968.

[9] Susumu SATO, "Applications of Liquid Cristal to Variable-Focusing Lenses," Opt. Re. Vol.6, No. 6, pp.471-475 (1999).