Multi-Electrically Driven Cylindrical Liquid Crystal Lens

Chun-Hsien Lee[1], To-Chiang Shen[1], Lin-Yao Liao[1], Chih-Wei Chen[1], Yi-Pai Huang[1], and Han-Ping David Shieh[1]

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

National Chiao Tung University, Hsinchu, Taiwan, 30010, R.O.C.

ABSTRACT

A liquid crystal (LC) lens with multi-electrically driven was proposed which can yield a desired profile of phase retardation over the whole LC layer. By adjusting the driving voltages, an LC lens owing a large aperture size with higher optical performance can be generated. Furthermore, this structure can be applied in many applications such as high F-number lens systems and 3-D displays.

INTRODUCTION

Tunable-focus lenses already exist in the nature. For instance, the human eye is a single-lens system with tremendously wide tunable focus range. The primary tuning mechanism is shape change, as controlled by the muscles in the eye, as shown in Fig.1 .

The LC lens has unique properties such as focal length is electrically tunable. Since there are no moving mechanical parts, they can smaller and lighter than the conventional tunable glass lenses. However, the major technical challenge of LC lens is generating a gradient refractive index profile.

In order to get better performance from the LC lens, designs of the electrodes and relative voltage to form the appropriate distribution of non-uniform electric field are very crucial. The conventional LC lenses were usually used two or three electrodes to produce gradient refractive index profile. [1-8] However, this method has a big issue of high aberration. Due to the slit is too wide in comparison with the lens in small voltage that electric field cannot affect the LC near the center, but in large voltage, the electric field changes between electrodes are too severe thus making the profile become disorderly as shown in Fig.2. Therefore, our group discussed the design with multi-electrode and modified the voltage relationship of the electrodes order to get appropriate gradient refractive index profile.

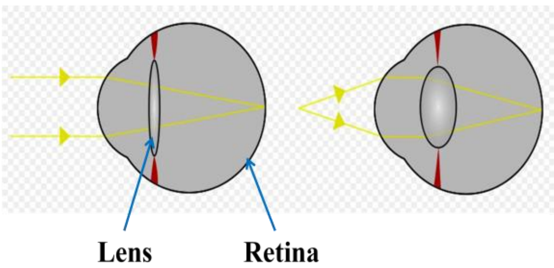


Fig.1 Imaging theory of the human eye

THEORY

The focal length of LC lens can be evaluated by using the Fresnel's approximation [11] as shown in Eq.(1).

$$f = \frac{r^2}{2 d_{LC} \Delta n} \quad (1)$$

where f is the focal length, r=D/2 (D is the lens aperture), d_{LC} is the LC layer thickness, and $\triangle n$ is the refractive index difference between the lens center and border.

By the transposition of Eq. (1), another represent of Δn can be expressed as shown in Eq. (2).

$$\Delta n = \frac{r^2}{2 d_{LC} f} = \kappa r^2 \quad (2)$$

Thus, Δn is a function of parabolic curve with r^2, where $\kappa = 1/2 d_{LC} f$ is a constant. We can also obtain the effective refraction index of the LC molecule in any orientation by Eq. (3).

$$n_{eff} = \frac{n_e n_o}{\sqrt{n_o^2 \sin^2\theta + n_e^2 \cos^2\theta}} \quad (3)$$

To investigate LC molecular orientation states in an inhomogeneous electric field, we used the commercial software 2DimMOS (autronic-MELCHERS GMBH) to calculate the LC director and export the LC director distribution data. Furthermore, we programmed the Eq. (1) and Eq. (3)

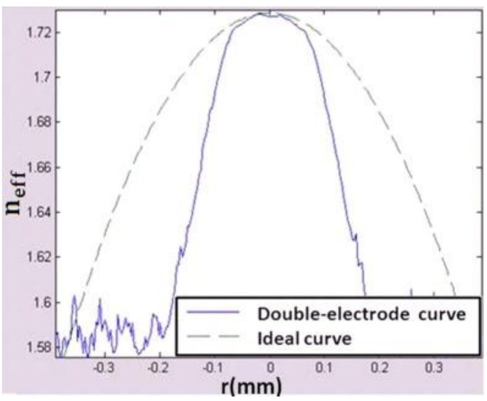


Fig.2 Simulation result of conventional LC lens and

the ideal parabolic curve

By the commercial software MATLAB and combine with the data which exported by 2DimMOS to calculate the refractive index profile under applying voltage. Also to judge the difference between the ideal curve and simulation curve, we define an error function (EF) as shown in Eq. (4). The simulated results of every structure compared with the ideal parabolic curve which drew by using the minimum and maximum effective refraction index.

$$EF = \sqrt{\frac{\sum_i^{aperture\ \ size}(S_i - P_i)^2}{aperture\ \ size}} \times 100\% \qquad (4)$$

The LC parameters used in the simulation are as follows: Merck nematic LC (E7), extraordinary refractive index n_e = 1.7472 and ordinary refractive index n_o = 1.5271, dielectric constants $\varepsilon_\perp$=5.2 and $\varepsilon_\parallel$ = 19.3, splay elastic constant K_{11} = 11.1pN, bend elastic constant K_{33} = 17.1pN. On the other hand, 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 becomes maximum.[12] Here we use a 300μm glass (ε_{glass} = 6.9) and lens width W_L=740μm as shown as Fig.3.

RESULTS AND DISCUSSION

In order to keep the parabolic profile and large Δn, a multi-electrode structure is applied as shown in Fig.4. Also the number of electrode and the ratio of W_E/W_S can affect the profile much. Thus, optimizing the number of electrodes and ratio of W_E/W_S is needed. From the simulation, we found that when the number of electrode is over 9 the changes of EF become saturate which the ration of W_E/W_S=1 as shown in Fig.4. And it was proved that under 9 electrodes the ration of W_E/W_S=1 is the most suitable ratio as shown in Fig.5.

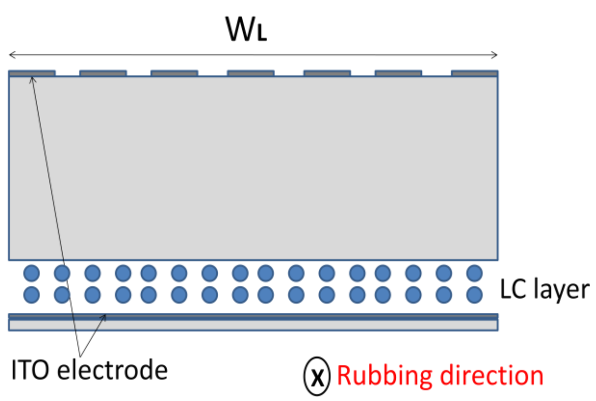


Fig.3 Multi-Electrically Driven Liquid Crystal Lens

(MDLC lens)

Also Fig.6, Fig.7 show the result of 9 electrodes with the ratio of W_E/W_S=1. Obviously with this design not only the effective aperture becomes larger but also the profile is more consistent with the ideal curve.

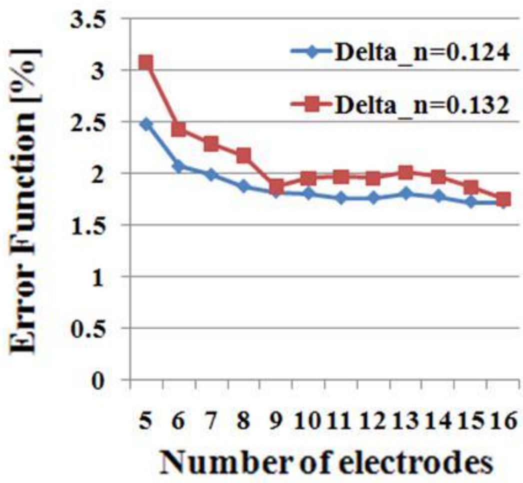


Fig.4 Simulation results of error function (EF) with number of electrodes

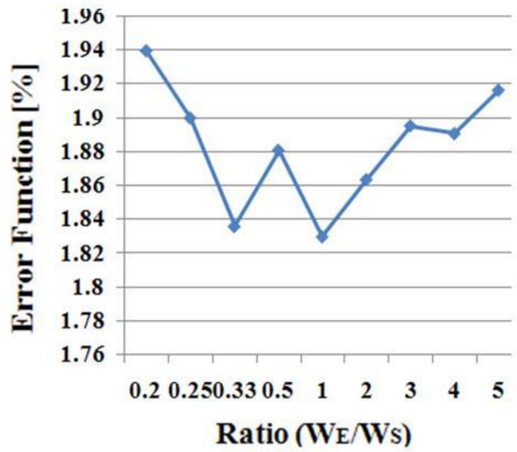


Fig.5 Simulation results of error function (EF) with 9 electrodes' Ratio (WE/WS)

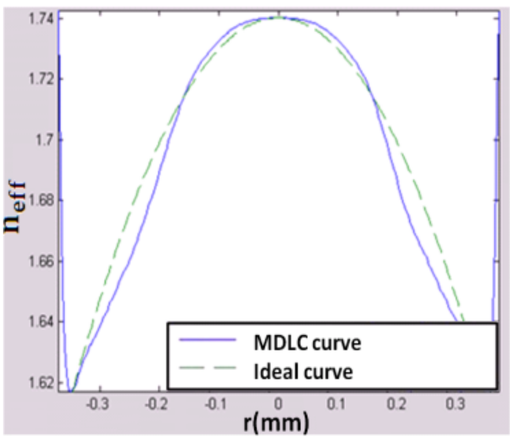


Fig.6 Simulation result of multi-electrode

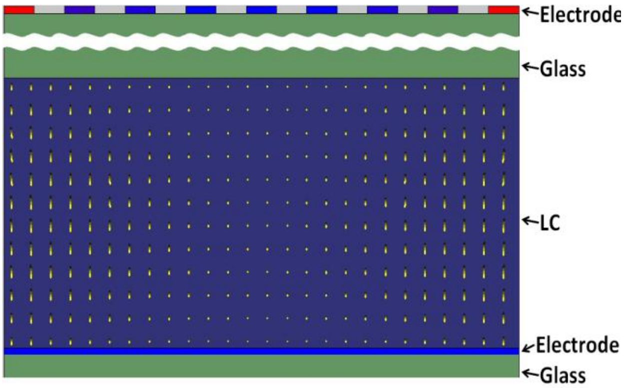


Fig.7 The simulation result of 2DimMOS

However, the electrodes of multi-electrically driven circle shape have been hardly fabricated. Moreover, the LC director will disorder at the electrode connect parts.[13] Therefore, the multi-electrically driven cylindrical LC lens have been proposed.

EXPERIMENT RESULTS

The MDLC cylindrical lens has been fabricated, as shown in Fig.8, and the optical performance has been measured, as shown in Fig.9. The rainbow color denotes intensity levels and white is the most powerful intensity. The cylindrical LC lens focuses the incident linearly polarized light into a line and focused on the CCD sensor. The focal length could be determined by finding the intensity peak value of the intensity distribution.

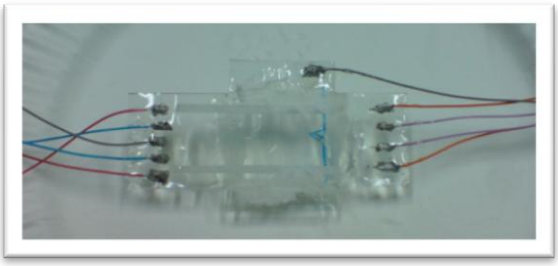
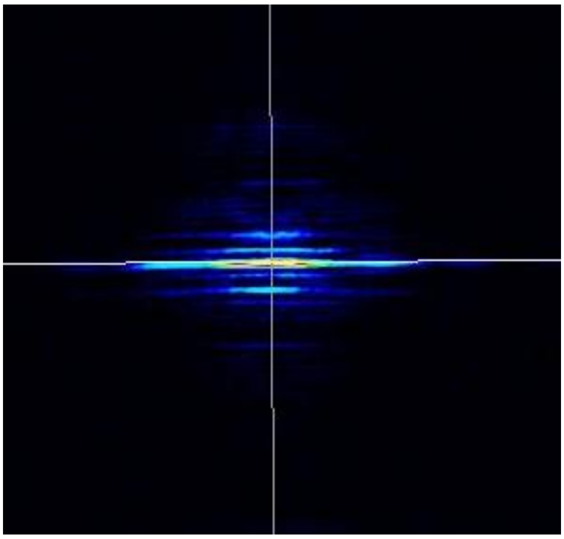


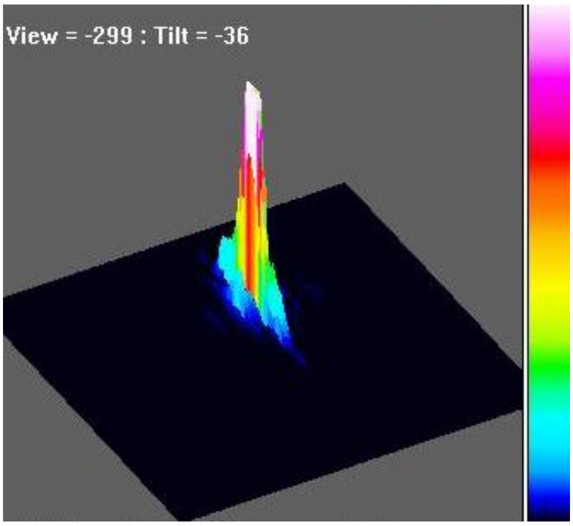
Fig.8 MDLC cylindrical lens sample

CONCLUSIONS

We have designed a multi-electrically driven LC lens and show the simulation and experiment results. In addition, the results suggest that our proposed MDLC cylindrical lens has a higher optical performance with large aperture size. This improvement is essential for designing a good optical performance of LC lens, especially for large aperture size. Hence, a simple structure with no LC alignment issue, smother △n curve and variable LC pitch can be realized by MDLC cylindrical lens.



(a)



(b)

Fig.9 Measurement results of MDLC cylindrical lens
(a) Over view
(b) 3-dimention view

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