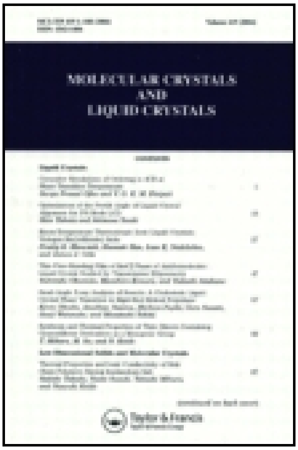

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ENHANCEMENT OF FOCUSING POWER OF LIQUID CRYSTAL LENS BY NEW CELL STRUCTURE

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An improved liquid crystal lens is proposed. Two liquid crystal layers are used in the new lens. The power of the new lens is about twice as large as the former one.

Keywords: liquid crystal lens; phase; power of lens

INTRODUCTION

A liquid crystal (LC) lens makes it possible to change the position of its focus by an external electric field [1,2]. Recently we have reported a new LC lens [3]. The electrode structure of the lens is simple and the lens can be of any size. Usually, a lens of large numerical aperture, or for a given size, a lens of short focal length, is desired. The focal length of the LC lens first decreases with the applied voltage, and when the rotation of the directors near the boundary of the lens aperture saturates and the directors in the central area continue rotating with the electric field, the profile of the refractive index seen by an incident light beam flattens, and the focal length begins to increase with the voltage. For an LC lens of diameter and LC (K15) thickness of 7 mm and 130 μm, respectively, the minimum focal length f_{min} is about 76 cm [3]. It would be possible to decrease f_{min} by using a thicker cell, but for the time constant of an LC cell is proportional to the square of the cell thickness, a thick LC lens would operate very slowly. In this paper, we propose a new cell structure to increase the focusing power of the LC lens. Two LC layers are employed. The new type

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LC lens has focusing power about two times larger than the former one, while its response to the external electric field is almost as fast as the former one.

EXPERIMENT

The former cell contains one layer of LC (Merck K15) sandwiched between two glass substrates. The lower substrate is coated with a transparent indium tin oxide (ITO) film as one of the electrodes and the surface with the ITO faces the LC layer. The upper substrate is coated with aluminum (Al) as another electrode and there is a round hole in the center of the coating. The surface without the Al coating faces the LC layer. Thus, there is an intermediate insulating layer between the hole-patterned electrode and the LC layer. The surfaces of the substrates contacting the LC are covered with polyimide (PI), and are rubbed in one direction so that the LC is aligned homogenously. The structure of the new lens is shown in Figure 1. The cell consists two K15 layers. The new cell is in fact a combination of two single-LC-layer cells. The cell parameters are shown in Table 1. The two ITO electrodes are electrically connected and the electric fields are produced by the voltage across the Al electrode and the ITO electrodes. An incident light beam polarized in the rubbing direction experiences induced phase shift approximately twice as large as it does with the former cell, and hence the lens of this work should have approximately double focusing power.

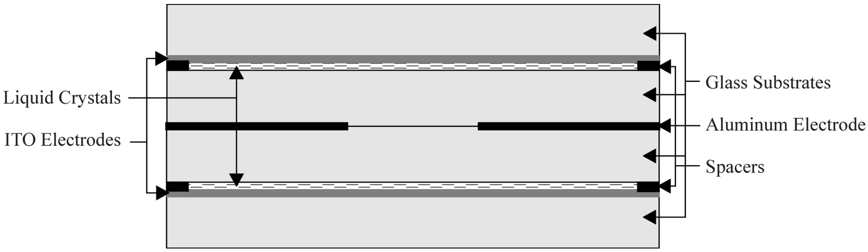
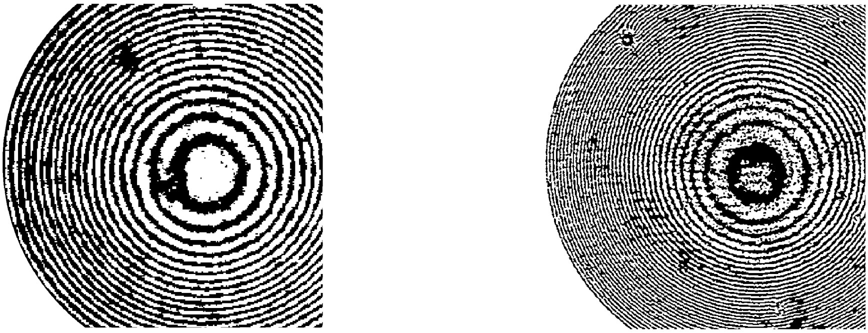


FIGURE 1 Structure of LC lens.

TABLE 1 Cell Parameters

Quantity	Value
Thickness of the LC	130 μm
Thickness of the Glass Substrate	1.3 mm
Diameter of the Hole	7.0 mm



(a) (b)

FIGURE 2 Interference patterns with former lens (a) and new one (b).

To test the new lens, a voltage of 65 V_{rms} is applied, and a stop of diameter of 5.0 mm is employed. The exiting light beam is interfered with a reference beam. The experiment is done with both the new lens and the former one. The interference patterns are shown in Figure 2. Figure 2(a) is the result of the former lens and Figure 2(b) that of the new one. The phase difference of two neighboring fringes is 2π. Let the fringe number be n, then the phase difference ϕ between the outmost rays and the central rays will be $2\pi(n-1)$. The number of the fringes in the direction perpendicular to the rubbing direction in Figure 2(a) is 19 and that in Figure 2(b) is 36. Then $\phi_{former} = 36\pi$ and $\phi_{new} = 70\pi$, and $\phi_{new} \approx 2\phi_{former}$. Due to the anisotropy of the LC directors, the number of fringes in the rubbing direction and in the direction perpendicular to the rubbing is slightly different.

Figure 3 shows the phase profiles of the exiting light beam at voltage of 65 V_{rms} in the rubbing direction. From the phase profiles the focal lengths can be deduced. It is found from Figure 3 that $f_{new} \approx f_{former}/2$.

For the thickness of the LC layers in the cell is the same as that of the LC layer in the former cell, the response and decay times of the new and the former lenses are almost the same.

The lens in this work is actually a combination of two of the former lens with a single LC layer, but unlike conventional thin lens combination [4], the power of the new lens is not simply equal to sum of the powers of the individual lenses. For both lenses, the electric fields in the LC layers are produced by the free electric charges in the electrodes and the induced electric charges at the surfaces of the glass substrates and the LC layers. The electrical charges in the new cell are shown in Figure 4. At the same voltage, the electric field in one LC layer in the new cell is different from that in the LC layer in the former cell. In one of the LC layers in the new

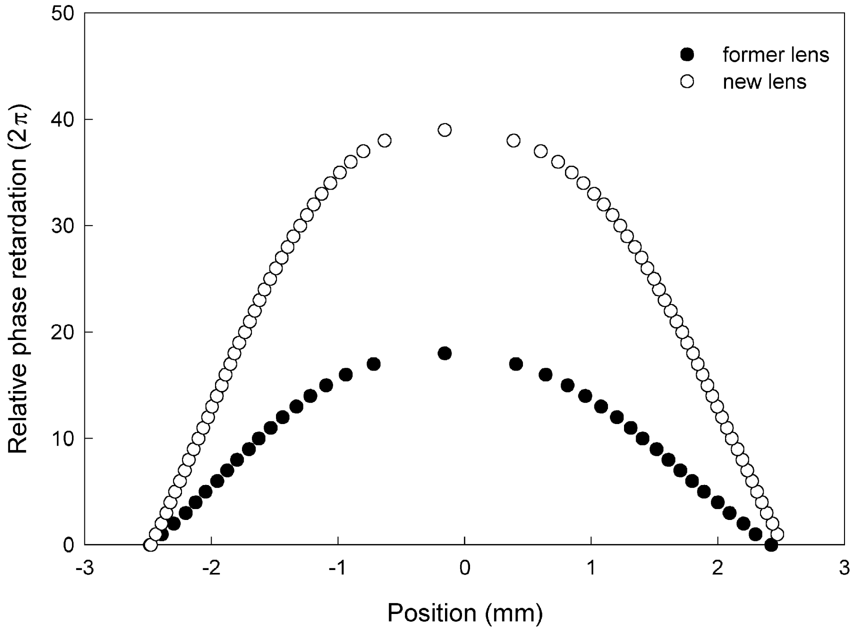


FIGURE 3 Phase profiles of light beam.

cell, there is an additional electric field from the charges at the other side of the Al electrode. The charges are in the other LC layer, the glass substrate between the Al electrode and the other LC layer, and the other ITO electrode. The LC layer is not completely shielded by the Al film from

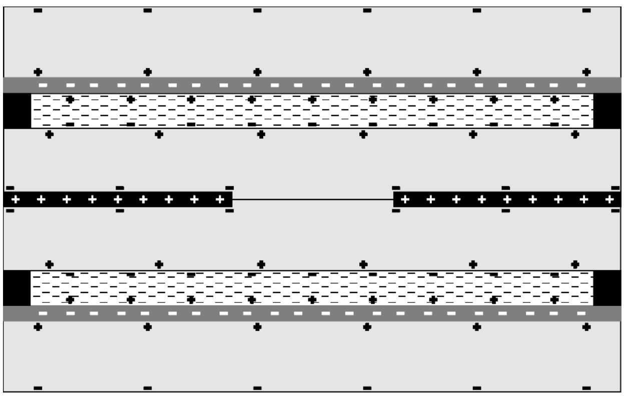


FIGURE 4 ■.

the influence of the outer charges, for there is a hole in the Al electrode. The introduction of the charged objects changes the distribution of the electric field in the LC layer. The effect of one LC layer in the new cell is then different from that of the LC layer in the former cell, and the new lens is not equivalent to two former lenses in contact. There is an interaction between the two LC layers and the objects surrounding them. The experiment shows that the interaction is small, and the new lens demonstrates a focusing power nearly twice as large as the former one.

CONCLUSIONS

An improved LC lens is proposed. Two LC layers are employed in the lens. At the same applied voltage, the focusing power of the new LC lens is about two times larger than the former one.

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