Low Voltage Driving Tunable Liquid Crystal Lens using Photoalignment Method

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Abstract

In this paper, we develop a method to prepare a liquid crystal (LC) lens using photoalignment technology. It's fabricated by utilizing variable pretilt angles of a photoalignment layer. By irradiating a Gaussian profile laser beam on a photoalignment layer, variable angles from 1º to 89º are formed. In this way, the tunable LC concave lens with negative power is fabricated and characterized. It requires low voltage control for its tunable feature, which results in low power consumption. Such lens can play a great role in many modern optical and photonic applications.

Keywords

Liquid crystal photoalignment; Concave lens; Tunable; Low power consumption.

1. Introduction

Due to the electrically tunable focal distance, LC lenses have many applications in optics and photonics, such as three dimensinal displays, imaging systems, microscopes, zooming systems, optical tweezers, etc [1-5]. Because of the massive applications, LC lenses still remain the heat and have been developed essentially in recent years. Compactness in size and easy tunability has made such lenses march into the market of protable mobile devices, such as mobile phones, cameras, etc. However, the power consumption, aperture and switching time remain as the main issues. In order to make tunable LC lens, a lens-like phase profile needs to be fabricated, which can converge or diverge to the propagationg wave. The traditional methods to acheive this are to control the LC director by nonhomogeneous cell gaps, patterned electrodes and nonuniform alignment, which will suffer from complicated fabrication processes, high power consumption and poor optical performance [3-5]. To improve such a situation, the tunable LC lense with spacially varying pretilt angles are preferred. Generally speaking, most of the LC devices are based on either planar or vertical alignment with pretilt angles of 0º-10º or 80º-90º. However, 10º-80º pretilt angels are difficult to fabricate. In order to acheive a varying changing of pretilt angles from 10º-80º, the common approaches

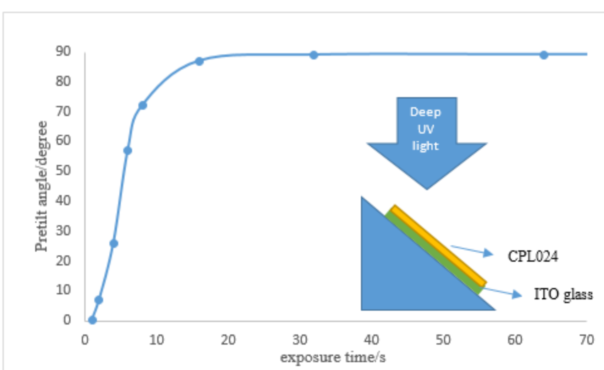

Figure 1. Left: Pretilt angle dependence on the exposure time (solid dots). Right: Pre-irradiation of the CPL024.

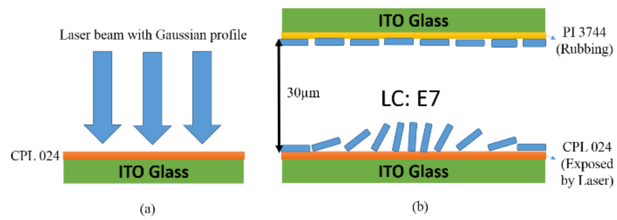

Figure 2. (a) Laser exposure; (b) LC cell structure of the fabricated LC lens.

include mixing of planar and vertical alignment materials [6], mixing of polyamic acids [7], stacked alignment layers [8, 9], etc. However, the fabraction of such methods are rather complicated. Here we report a method using a photoalignment layer exposed by a laser beam with Gaussian profile to provide spacially varying pretilt angles, which can form a lens-like phase profile.

2. Methodology

The photoalignment material CPL024 [from Dai-Nippon Ink and Chemicals (DIC)] is used in our experiments. It's a cross-linking polymer, which can be given a broad range of pretilt angle from 1º to 89º depending on the irradiance doses. The relationship between the pretilt angles and irradiance doses is shown in Fig. 1. Firstly, the 0.5% wt/wt concentration CPL024 solution is spin coated on top of ITO glass. After the evaporation of the solvent, the alignment layer is exposed with two-step irradiation. Firstly, we pre-irradiate it for one second to define the preferred azimuthal direction, which will provide the pretilt angle of ~1º. The process is shown in Fig. 1 (left). The intensity of the polarized light for pre-irradiation is 3mW/cm2 for 365nm, 3mW/cm2 for 310nm, 1.8 mW/cm2 for 280nm and 2.8mW/cm2 for 254nm. Then we expose the substrate with a laser beam, which has a Gaussian profile, as shown in Fig. 2 (a). After this, we assemble the cell with another substrate coated with PI3744 (from Chisso Co. Japan), a planar polyimide, as shown in Fig. 2 (b). Finally a LC material E7 (from Merck) with Δn=0.225 is injected into the cell. From Fig. 2(b), one can see that the LC molecule will have pretilt angles varying from ~89º to ~1º from the center to the edge of the lens profile.

3. Result

In order to characterize the tunable LC lens we made, the phase profile has been measured. A red filter with transmission peak at 650 nm were used to filter the white light source to narrow band light. The fabricated LC lens was placed under microscopy between crossed polarizers with azimuthal direction at 45º in the plane. Then A AC signal with 1 KHz frequency was applied to tune the LC lens. The microscopic photographs under different voltages are shown in Fig. 3. The transmittance at different points of the lens profile can be calculated using Eq. (1).

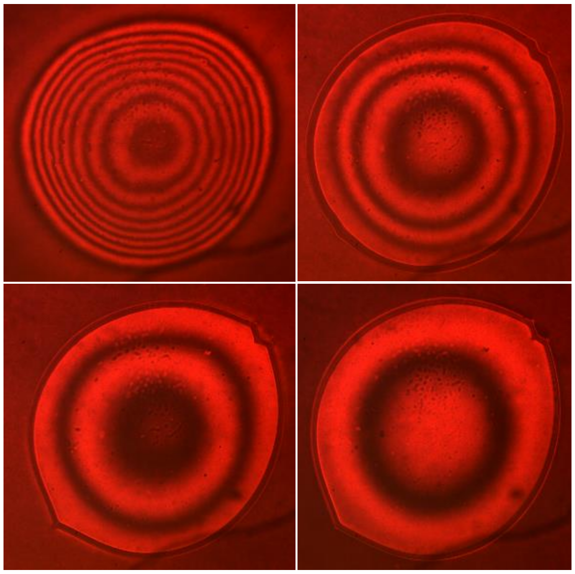

Figure 3. Lens profiles under different voltages (From top left to bottom right the voltages are 0V, 0.9V, 1.4V and 1.8V)

$$T = \sin^2(\frac{\pi d \Delta n}{\lambda}), \quad (1)$$

In the above equation, d is the cell gap, Δn is the average birefringence and λ is the light wavelength. The transmittance values of the profile from the center to the edge were extracted from the photos, which were then used for the calculation of the retardation parameter. The retardation parameter is defined as $\frac{\pi d \Delta n}{\lambda}$. The retardation parameter profiles for the fabricated LC lens at different voltages are shown in Fig. 4. All the retardation parameter profiles show very fitting parabolic character, which is the best case for lens design. The fitting line is the most suitable

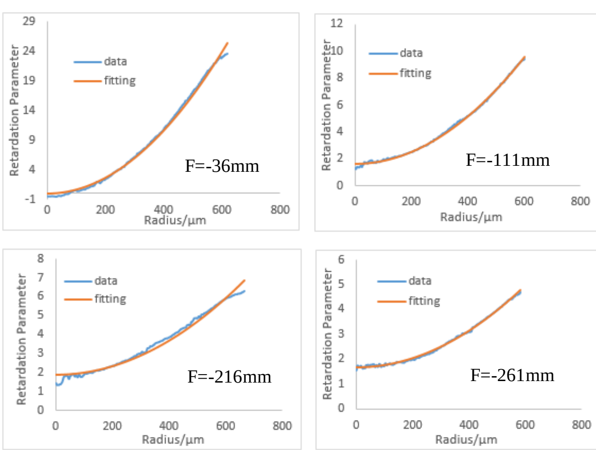

Figure 4. Retardation parameter profiles under different voltages. (From top left to bottom right the voltages are 0V, 0.9V, 1.4V and 1.8V) *Data* line represents the original experimental data, while the *fitting* line represents the parabolic fitting with the former. F represents the focal distance of the LC lens.

parabolic approximation of the experimental data, which fits very well with the original retardation parameters.

The focal distance of the LC lens can be calculated by Eq. (2), as shown below:

$$f = \frac{r^2}{2d(n_{e2} - n_{e1})} \quad (2)$$

where r is the radius of the LC lens, d is the cell gap and $n_{e2} - n_{e1}$ is the effective refractive index difference between the center and edge of the LC lens. The calculated results are shown in Fig. 4. From the results, one can see that the higher the applied voltage is, the larger the focal distance of the LC lens becomes. With a large enough voltage, the focal distance will become infinite. But only 1.8V is applied, it will be changed with a large scale from 3.6cm to 26.1cm, which means the LC lens can be tuned in a broad range by a relatively low voltage, resulting in low power consumption.

4. Summary

This paper demonstrates an approach to fabricate a low voltage driving tunable LC lens using photoalignment technology. By irradiation different doses of light on the alignment layer, the generated pretilt angles vary from ~1° to ~89°. Lenses with such pretilt angle profiles can be controlled by a extreme low electrical field, which is an important advantage over other lenses. In addition, the focal distance of the fabricated LC lens can be controlled in a broad range with a relatively low driving voltages. Optmizing the LC and cell parameters can decrease the operating voltage further. Moreover, this approach also indicates that certain LC alignment structures can be achieved by irradiation of light sources with specific profiles.

5. Acknowledgements

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6. Reference

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