Surface Control of LC Alignment for Creation of Liquid Crystal Lenses Arrays

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Abstract

New photosensitive alignment materials, capable to obtain pretilt angle from 90 to 0 degree in single technological process of UV exposure, are developed. The novel technological method for fabrication LC lens and LC lenses arrays has been developed based on new pretilt angle gradient alignment materials. Laboratory samples of voltage tunable LC lens and LC lenses arrays are obtained and characterized. The developed low cost fabrication technology of tunable micro-lenses arrays based on photosensitive alignment materials has low complexity and is perspective for light field technology applications.

Author Keywords

Liquid crystal lenses array, pretilt angle, liquid crystal alignment.

1. Introduction

The control of both the intensity and the viewing angle of display pixels is highly anticipated by light-field display technology. The functional properties can be achieved though combination of LCD panel with switchable liquid crystal (LC) micro-lenses array that allows controlling the viewing angle. Numbers of approaches of tunable LC lens fabrication are known for decades. However impractical high complexity of single LC lens element limits its scalability for tunable micro-lenses array module.

The advanced surface control of liquid crystal alignment conditions of novel alignment layers with tunable pretilt angle through light exposure [1] opens up technological process for fabrication of liquid crystal lens system [2] by generation of predefined parabolic gradients of pretilt angle [3]. The photosensitive orienting layer is subjected to local irradiation with a parabolic UV-B radiation intensity distribution profile, forming the lens aperture in the LC layer, by changing the pre-tilt angle on the surface from 90° to 0°.

2. Creating an LC lenses array

We have developed an orienting material, in which the pretilt angle is determined by the irradiation dose of the orienting layer with UV radiation. Depending on the radiation dose, the pretilt angle can be set within the range from 90° to 0°. (Fig.1).

When using coherent light (laser radiation) or light from a mercury lamp (narrow radiation lines), it is not possible to obtain a smooth change in the tilt angle LC within the generated lens. The reason for the resulting inhomogeneity is the coherence of light, resulting in areas of different intensity, known as speckles. The solution to this problem is to use an LED light source.

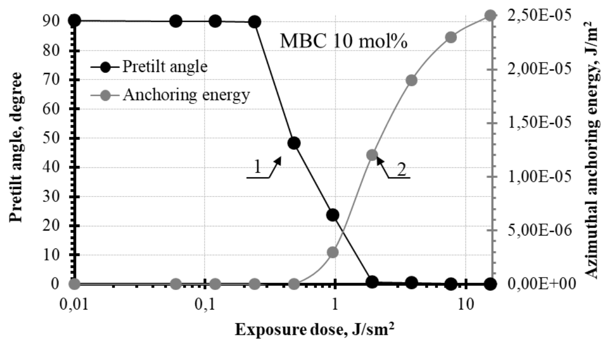


Figure 1. Pretilt angle and azimuthal anchoring energy dependence on the exposure dose for MBC10 photosensitive gradient polymer alignment material

Photosensitive alignment layer exposure with parabolic intensity distribution of light brings to formation of bell-shaped pretilt angle distribution for lens-like LC structure (Fig. 2).

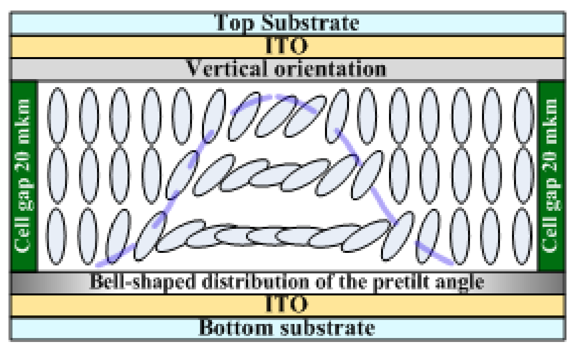


Figure 2. The structure of LC lens cell at 0V applied voltage

We utilized UV-B LED exposure system with intensity maximum at 308 nm wavelength to fabricate LC lenses. The exposure system based on UV-B LED has an output beam with a profile close to parabolic and 450 mW light power. It has 1 mm diameter of output beam at distance h=4 mm. The light intensity distribution for different exposure distances h from the sample surface with alignment layer to the output lens of the illumination system is shown on Fig.3. We estimated that the optimal exposure distance h = 5.5 mm.

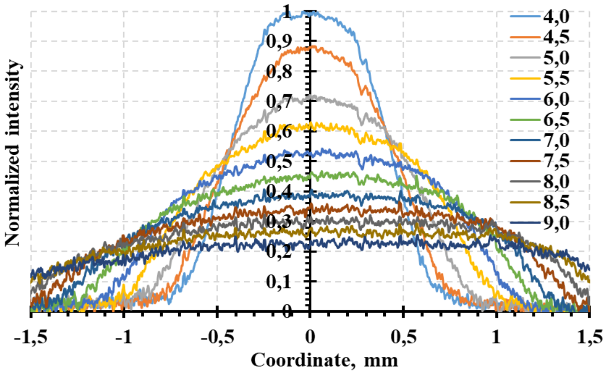


Figure 3. Radiation intensity distribution of the beam of the UV-B LED system for different exposure distances

The intensity spot of focused non-polarized non-coherent light of contemporary UV-B/UV-C LED is excellent to form a LC lens within the area of alignment material exposure (Fig.4). The exposure dose determines the size of each LC lens that can be as small as 200 μm in diameter (Fig. 4). Needless to mention is that the application of the LED exposure system provides superiority of complete incoherence of the emitted light over various mercury lamp systems. The low coherency of mercury lines results into interference speckling of the exposure area and randomization of exposure intensity distribution profile. The latter is critical for obtainment of smooth surface gradients of pretilt angle, required for high quality LC lenses, due to high sensitivity of the photosensitive alignment layers.

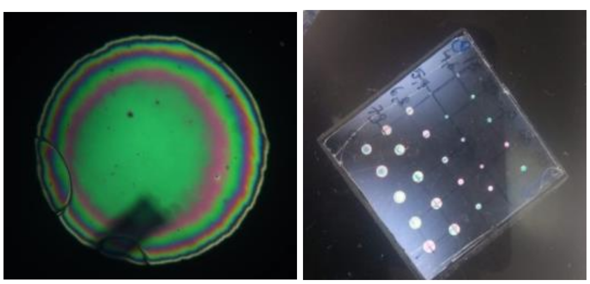
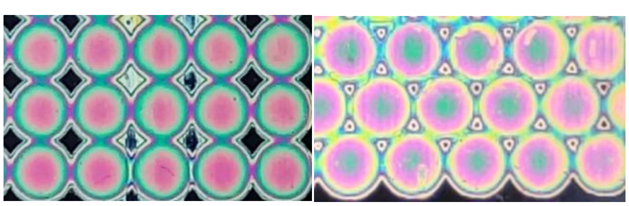


Figure 4. The LC lens sample and the array of LC lenses of different sizes

The exposure time of the alignment layer for the formation of a parabolic profile of phase retardation distribution of the LC lens is 15 s with 1W UV-B LED system. It is possible to obtain various types of packing lenses in an array. We used XY translation stage, computed coordinates and generated square packing (Fig. 5a) and triangular packing (Fig. 5b) of LC lens arrays. The lens period or the distance between the centers of the lenses is 1.85 mm.



a) b)

Figure 5. LC lenses arrays with a) square packaging and b) triangular packaging of LC lenses elements

The LC lens images were taken with the polarized microscope camera, placingthe LC cell at 45 degrees between crossed polarizers. An alternating voltage from 0 to 10 V with a frequency of 1 kHz was applied to the LC cell (Fig. 6).

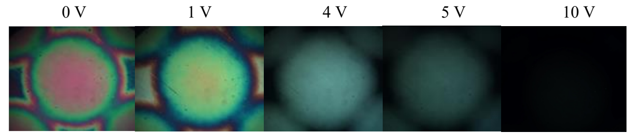


Figure 6. The microphotographs of LC lens based on pretilt angle gradient photosensitive alignment layer for applied voltages 0, 1, 4, 5 and 10 V

Applying low voltage levels to ITO electrodes from 0 to 5-10V gradually tunes the focal length of the LC lens from initial value to infinity and controls the viewing angle (Fig. 7).

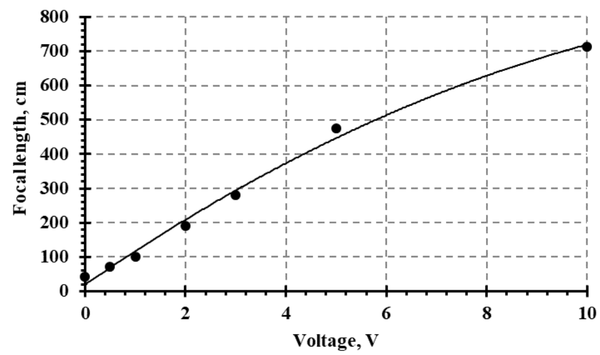


Figure 7. The focal length dependence on the applied voltage measured for LC lens with lens diameter 3 mm

3. Characteristics of LC lenses

The size of the manufactured lenses was based on the convenience of studying their phase characteristics. The phase retardation LC layer Ψ was measured using a polarizing microscope, determining from the transmission spectra of the birefringent layer of the lens in crossed polarizers on the coordinate from the center of the lens (Fig. 8).

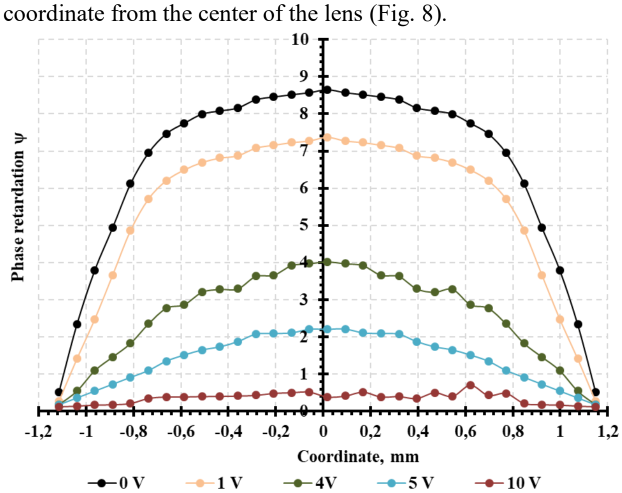


Figure 8. Experimental distributions of phase retardation measured within LC lens for different levels of applied voltage

The focal length of the LC lens is subject to lens diameter. The focal length F of LC lens can be calculated by the next formula:

$$F = \frac{(D/2)^2 - (\Delta n_{eff} \cdot d)^2}{2 \cdot \Delta n_{eff} \cdot d}, \quad (1)$$

where D is the lens diameter , Δn_{eff} – the maximum value of the effective birefringence, d – LC cell gap.
According to our estimations 2.5 mm focal length is reached for the LC lens with diameter 200 µm, cell gap 20 µm and refractive index anisotropy of liquid crystal Δn = 0.2.

The thickness of liquid crystal layer or the cell gap of LC lens can vary from a few to tens of micrometers (i.e. ~50 µm), the birefringence of known LC materials can also vary from 0.1 to 0.4 µm [5]. This makes it possible to obtain arrays of LC lenses with focal length as low as few centimeters only (Fig. 9).

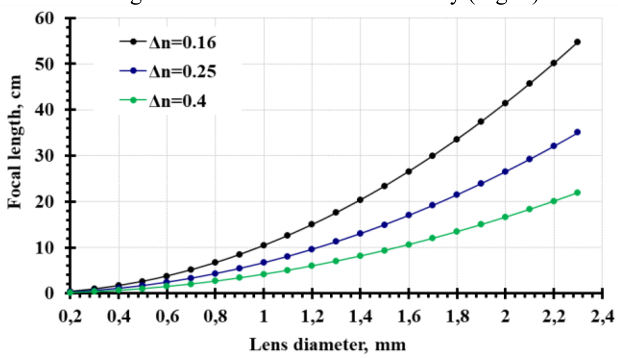


Figure 9. Calculated dependence of focal length of single liquid crystal lens on the lens diameter

4. Conclusion

The series exposures of single alignment layer allow the target pattern of tunable LC lenses array within one LC cell fabrication process. Thus novel alignment materials reduce the complexity of liquid crystal lenses array creation process making it comparable to LCD panel or less. Simple and technological method of LC lens arrays fabrication based on UV LED exposure of photosensitive liquid crystal alignment layer is proposed. The developed photosensitive alignment materials possess high azimuthal anchoring energy of 2.5*10^{-5} J/m^2 and are capable to induce the LC pretilt angles in a full range of 0 – 90 degree. The materials are suitable for low-temperature process 60-80°C, while the LC lens technology is compatible both to glass and plastic substrates. Single uniform electrode is used to control the LC lens array. Control of the focal length of the LC lens carried out by control voltage in the range of 0-10V to the electrodes of the LC lens cell.

5. Impact of Present Research

Innovative photosensitive alignment materials in combination with novel UV LED light exposure system open up low cost and technological method for fabrication of tunable LC lenses arrays required for various applications of light field technology.

6. References

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