Fabrication of the Outer type-Dynamic Microlens Array using Surface-Stabilized Ferroelectric Liquid Crystal

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Abstract

We fabricated the outer type-dynamic microlens array using a surface-stabilized ferroelectric liquid crystal, UV curable polymer and the stacked liquid crystalline polymer. The outer type-microlens array has a lower driving voltage and fast switching property. It is applicable to a variety of optical systems.

1. Introduction

Various type of dynamic microlens arrays (DMLA) based on the liquid crystal have been gradually introduced for application to optical systems, such as optical storage device, optical communications, and image integration component for future three-dimensional displays [1-3]. Among them, the DMLA using a surface relief structure and stacked liquid crystalline polymer has been studied in our research group [4].

In our previous studies, we have investigated both theoretically and experimentally the characteristics of the microlens based on nematic liquid crystal (NLC) and ferroelectric liquid crystal (FLC). Though the NLC microlens has a good focusing property, it has a slow response time due to intrinsic property of NLC and is not sufficient for optical system requiring fast response time.

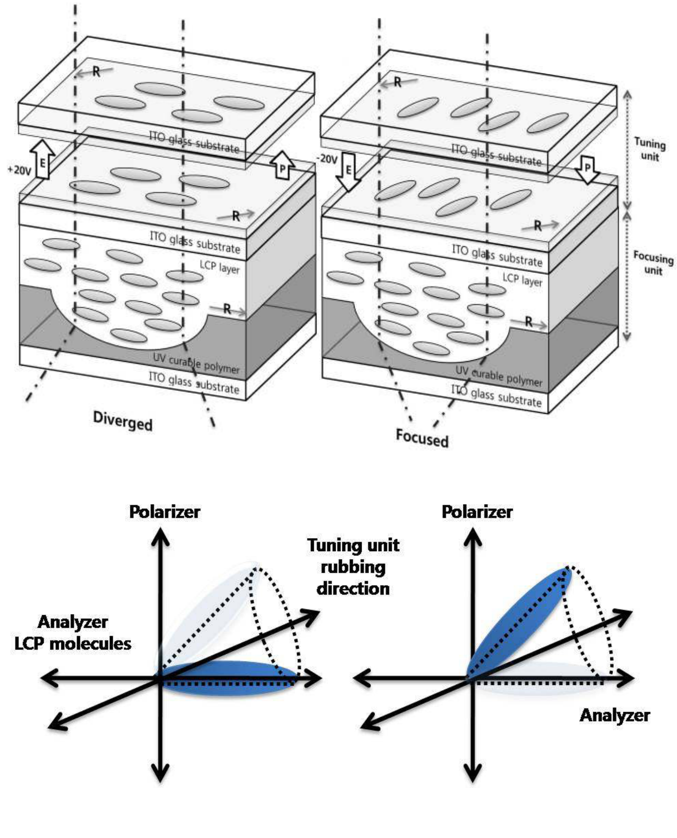
Recently, several attempts have been made to obtain a fast-switching microlens array using ferroelectric liquid crystals because of their fast switching time and bistable electro-optic effects [5]. Although these approaches lead to a fast switching device for optical applications, the structural unstability is pronounced still with smectic LC, especially in non-flat surface undulation like lens structure. Moreover, they require high voltage due to longer distance between electrodes and complicated switching mechanism due to the deformed electric field by the non-flat structure of passive lens.

In this paper, we propose the outer type-surface stabilized ferroelectric liquid crystals (SSFLC) microlens array as shown in Fig. 1. In this configuration with the tuning unit separated from the focusing unit, outer type-microlens using a SSFLC has many merits such as a simple fabrication process, lower driving voltage, and good focusing property due to better LC alignment property.

2. Experimental

For proposed microlens, we first fabricated focusing unit. The UV curable polymer (NOA60, Norland Products Inc.) was spin-coated with two steps process on the ITO (Induim-tin-oxide) glass substrate to obtain uniform thickness (~ 20 μm) for good lens properties. The first step was done with a rate of 500 rpm for 10 sec and subsequently the second was done with a rate of 1700 rpm for 30 sec. Under patterned chromium photomask, the sample was exposed to the UV (λ=365nm) light for 100 sec. During this time, monomers in the UV curable polymer are diffused from low intensity region to high intensity region. Due to the spatially modulated UV light through the patterned photomask, monomers in the blocked region are diffused to the unblocked region to maintain their relative concentration. At the same time monomers undergo the polymerization. As a result of anisotropic diffusion and polymerization, the surface relief structure is created. For full-curing, the sample was exposed to UV light for about 7 min without photomask.

To align the liquid crystalline polymer (LCP), the RN-1199 (Nissan Chemical, Japan) as an alignment layer was spin-coated onto the UV curable polymer.



(a) Field up (+20V) **(b) Field down (-20V)**

Fig. 1. Configuration diagrams of proposed outer type-SSFLC microlens array system.

(a) **(b)**

Fig. 2. Polarizing Microscope image showing the alignment state of a SSFLC cell under crossed polarizer : (a) The optic axis of polarizer (or analyzer) is parallel to the easy axis of the FLC molecules (b) Rotating image 45^o with respect to the optic axis the polarizer (or analyzer)

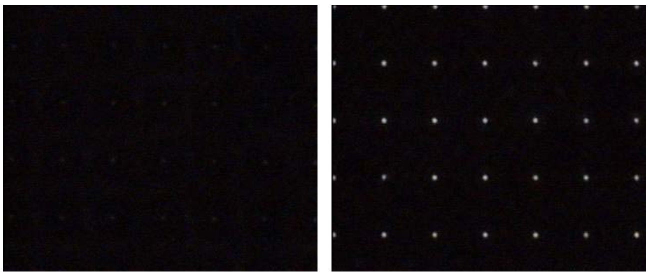
To achieve a homogeneous alignment state, rubbing process was carried out. Then LCP material (RMS03-001C, Merck) was spin-coated on the alignment layer at rate of 500 rpm for 10 sec and 1000 rpm for 60 sec, and the solvent in LCP compound was evaporated at 60^{o}C for 1 min before the UV exposure under nitrogen circumstance for 25 min for polymerization of the LCP material. After this process, a homogenous alignment state was obtained. The presence of LCP layer shows a good focusing property. The refractive indices of UV curable polymer and LCP material are n_p=1.56, n_e=1.684, and n_o=1.529, respectively.

For fabrication of tuning unit, we prepared two ITO glass substrates that were assembled with the cell gap 1.8 μm, which suppresses the helical pitch of FLC material and obtained the highest transmittance. The rubbing direction of two substrates was anti-parallel. The angle between the LCP molecular and FLC rubbing directions is 22.5^o, which is a measured FLC cone angle. The FLC material (Felix-015/100, Clariant) was injected above the clearing point (86^{o}C). Several methods have been proposed for the better SSFLC alignment state [7-9]. The selected method in our group is a low-frequency AC electric field, PI-RN1199 alignment films and detailed temperature control in the FLC phase transition. The fabricated cell was cooled down slowly by 0.1^{o}C/min during the phase from SmA to SmC* (83^{o}C~72^{o}C) to obtain a fine alignment state. The rest phase section was cooled down by 1^{o}C/min. The extraordinary and ordinary refractive indices of used FLC material are 1.664 and 1.490, respectively. Fig. 2 shows the clear alignment state of SSFLC. Finally, for outer type-microlens array using SSFLC fabrication, the tuning unit and focusing unit were attached each other.

3. Results and discussion

Fig. 3 is microscopic images showing switching characteristics of focal intensity at the proposed outer type-microlens array system under the crossed polarizer. In the field-up state (plus polarity), the polarization of incident light is perpendicular to the FLC molecules. Then, this polarization parallel to fast axis, n_o (=1.4903) of the FLC molecules is also parallel to the fast axis, n_o (=1.529) of LCP and then, the light diverges due to the refractive index difference between n_o (=1.529) of LCP and UV curable polymer n_p (=1.56). Consequently, it becomes black state because the polarization of the beam is perpendicular to the optic axis of the analyzer. In the field-down state (minus polarity), the linear polarization tilted by 45^o from both fast and slow axes, n_e (=1.6639) and n_o, respectively of the FLC molecules is rotated by 90° coincident with the slow axis, n_e (=1.684) of the LCP layer. Consequently, the beam is focused because n_e (=1.684) of the LCP layer is larger than the refractive index of UV curable polymer and becomes the white state because the polarization of the beam is parallel to the optic axis of the analyzer.

Fig. 4 shows the beam intensity profiles at the applied voltage of ±20V. We know that it exhibits a good focusing property. Fig. 5 shows the response time of the fabricated cell. The rising time and falling time which are measured by oscilloscope are 44 µs and 26 µs, respectively. The response time is suitable for the optical system that requires fast switching property. In addition the lower driving voltage is observed from Fig. 5. As a result, we expect that the proposed microlens array is applied to the real-time optical system, high reliable optical switch, and the optical storage device



(a) +20V (b) -20V

Fig. 3. Polarizing Microscope images showing focal switching of the proposed outer type-microlens array using the SSFLC under crossed polarizer: (a) at field with plus polarity, (b) at field with minus polarity.

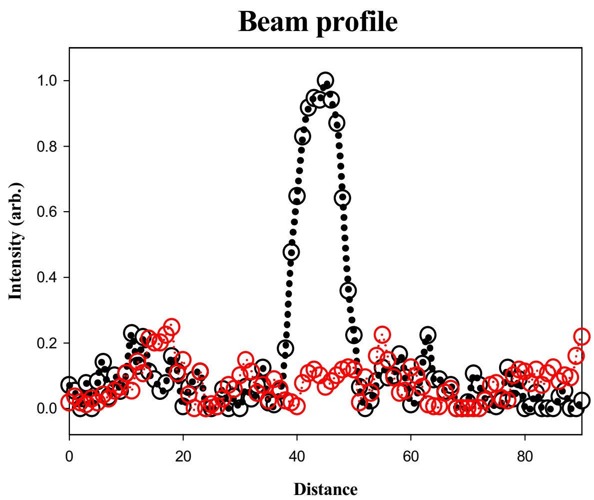


Fig. 4. Beam intensity profiles at the applied voltage.

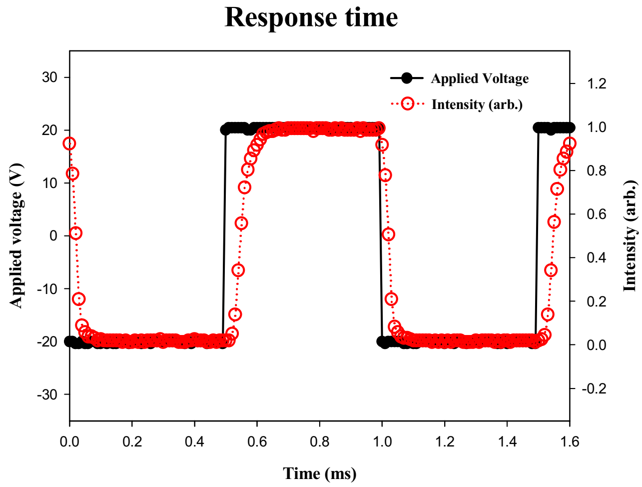


Fig. 5. Response time of the fabricated outer type-microlens array using SSFLC.

4. Summary

We fabricated the outer type-dynamic microlens array using Surface-stabilized ferroelectric liquid crystal, UV curable polymer, and liquid crystalline polymer. Due to this separation of tuning unit and focusing unit, driving voltage can be reduced much as compared with previous work and it has also a good focusing characteristic by LC alignment. Also the proposed microlens array has a simpler fabrication process because each part is fabricated separately. In the event, we guess that it can be used more simply and easily for optical systems such as a optical storage device, optical communications which requires fast switching and image integration component for future three-dimensional displays.

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6. References

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