# Fabrication of a microlens array using a birefringent layer and ferroelectric liquid crystal

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## Abstract

*A new concept of the microlens array is fabricated using a birefringent layer on the concave microlens array. The stacked layers of liquid crystalline polymer (LCP) and the UV epoxy focus an incident light due to the surface relief structure. The ferroelectric liquid crystal layer was added to control the focusing intensity with a fast switching time.*

## 1. Introduction

The liquid crystal (LC) microlens array can be used for 3D display, information processing, integrated optics and optical communications [1-3]. Recently, a number of researches have been reported to develop high-performance microlens by using electrode pattern and surface relief structure. However, the limits of microlens array such as high operational voltage, slow response time and a delicate fabrication process should be improved for practical applications [4- 6].

In this paper, we suggest a microlens device which consists of a focusing and a tuning section as shown in Fig. 1. The focusing section is fabricated by the stacked layer of liquid crystalline polymer (LCP) on the concave microlens structure of the UV epoxy. The focusing section has focusing ability for incident light depending on the polarization direction due to the birefringent characteristics of LCPs. The ferroelectric liquid crystal (FLC) layer which has fast switching characteristics is adopted in the device to control the incident light polarization.

## 2. Experimental

The fabrication process of the focusing section is shown in Fig. 2. As the first step, the UV-curable polymer material (NOA60, Norland) was spin-coated on the cleaned ITO substrates at the rate of 1000rpm for 10 sec and followed by the rate of 4000rpm for 30 sec. Then, the obtained thickness of the spin-coated layer was about 18μm. To produce surface relief structure on the UV-curable polymer layer, the UV ($\lambda$=365nm) light was irradiated onto the UV-curable polymer for 10 sec through a patterned photomask. The source of UV light is a Xenon lamp power-driven at 300W. The monomers in the UV-exposed region are polymerized first and cause an anisotropic diffusion from the UV-blocked region to the UV-exposed region to keep up their relative concentration [7]. With these polymerization and diffusion, the surface relief structure was created. To harden the shape of the surface, another curing with UV light irradiation was carried out for 5 min. without the photomask. For the alignment of LCP molecules, we spin-coated a homogeneous alignment layer of RN-1199 (Nissan Chemical) and rubbed the layer to anti-parallel direction. Then, LCP material (RMS03-001C, Merck) was spin-coated on the top of the homogeneous alignment layer at the rate of 3000rpm for 30 sec. The LCP layer coating process was repeated to obtain flat surface of the LCP layer. The spin-coated layer was cured by a baking oven at 60° for 5 min, followed by the UV irradiation for 30 min. With these fabrication processes, we produced a microlens array where the widths of LCP and UV-curable polymer layer were 6μm and 14μm, and the diameter and inner depth of each microlens were 200μm and 4μm, respectively. The ordinary and extraordinary refractive indices of the LCP and the refractive index of UV-curable polymer were 1.529, 1.684and 1.56, respectively.

To fabricate the tuning section which is able to control an incident light polarization, FLC material

(Felix-016/100, Clariant) was filled on the flat focusing section at isotropic phase (>98°C) by dropping method. The FLC material was then sandwiched between the microlens array substrate and an ITO-coated substrate with 3μm-cell gap spacers. To obtain stable FLC alignment, it was cooled slowly (0.1℃/min) to the SmC* phase through the N* and the SmA phase, with the applied alternative electric field of ±50V (50Hz). The cone angle of the FLC is 25° at room temperature, the extraordinary and the ordinary refractive indices of the FLC are 1.653 and 1.469, respectively.

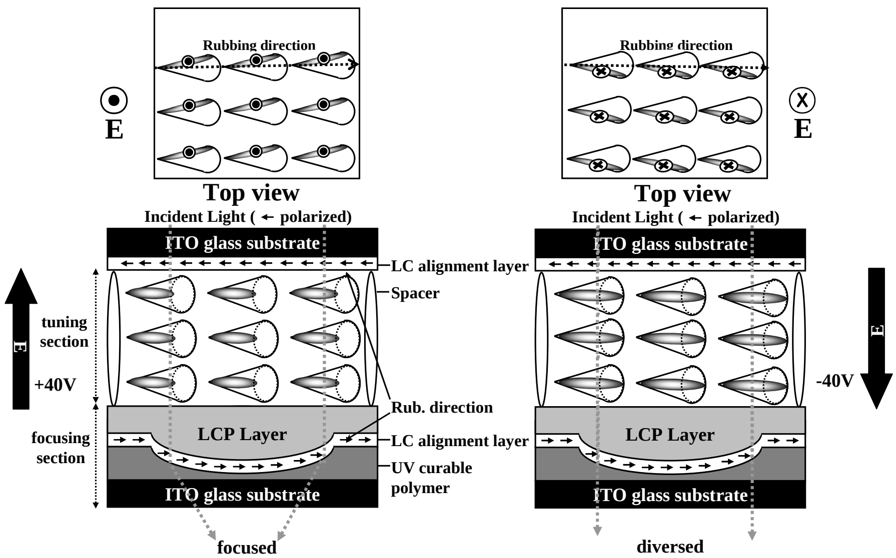



**Fig.1. Schematic diagrams of the proposed FLC microlens array with two bistable states**

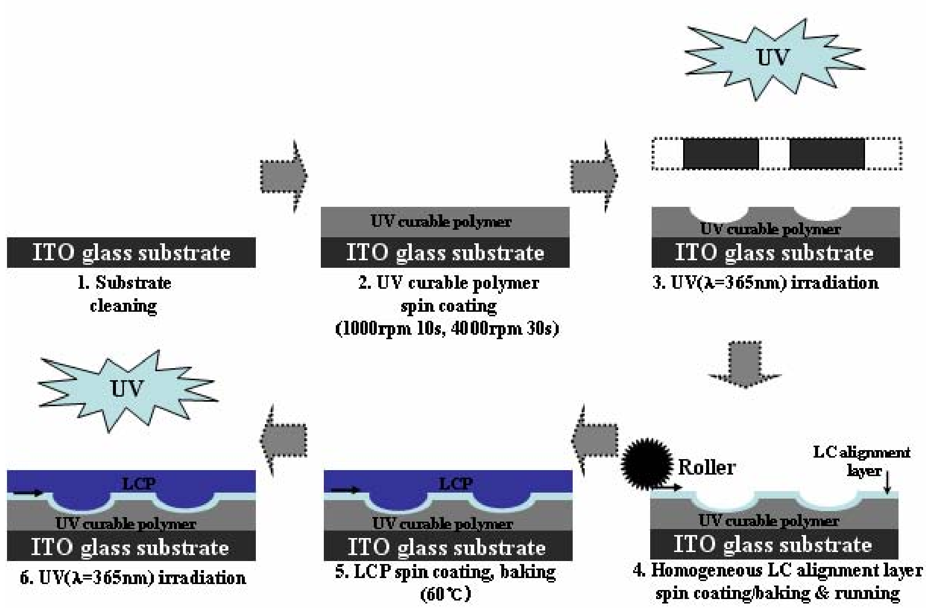



**Fig. 2. Fabrication process of the focusing section**

## 3. Results and discussion

SEM cross-sectional image of the focusing section is shown in Fig.3. From the image we could confirm the concave lens structure and its flat boundary. Optimizing spin-coating and surface treatment, we fabricated total 20μm-thick concave microlens which is thin enough to minimize the voltage drop effect caused by the microlens thickness. It is noted that the flat surface of the focusing section can eliminate the disclination and the non-uniform LC behavior, so that the quality of focal image can be improved.

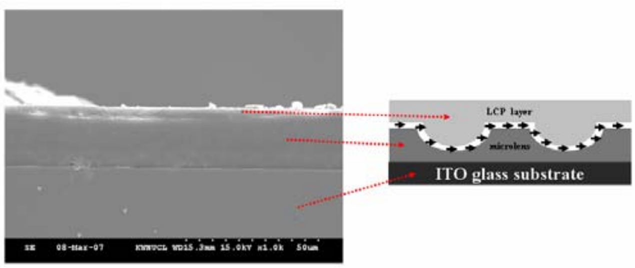
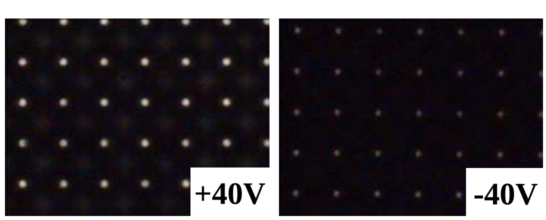


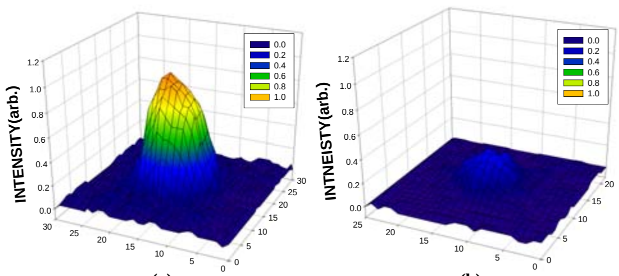

**Fig. 3. SEM cross-sectional image of the focusing section**

The bistable characteristics of the microlens array were examined by observing the status of the focused image. When the director of LCs were parallel with the aligned direction of LCPs, well focused image was observed at +40V as shown in Fig. 4(a). Since the effective refractive index of the LCPs is greater than that of the UV curable polymer the light is focused. In this case, we can obtain the maximized focusing intensity. When we applied -40V, the ease axis of LCs is rotated by 48° (cone angle of FLC) due to the spontaneous polarization of FLCs. This rotation of the ease axis of LCs reduced the focused intensity as shown in Fig. 4(b).




**(a) (b)**

**Fig. 4. The focusing characteristics of the FLC microlens array: (a) Focused image at +40V (b) Diverged image at -40V**




(a) (b)

**Fig. 5. The focusing intensity profiles of the FLC microlens with applied voltages: (a) Beam profile at +40V (b) Beam profile at -40V**

Figure 5 shows the beam intensity profiles of the microlens array with the applied electric field of +40V and -40V, respectively. The beam intensity profile of the maximized intensity case is about 3 times greater than that of the minimized intensity. The measured focal length of the microlens was 10.5mm ± 0.2mm.

Figure 6 shows the switching properties of the microlens array when the electric field of ±40V is applied to the microlens array. The measured switching time of the microlens array, the rising and falling time, are 74 $\mu s$ and 68 $\mu s$, respectively. Note that the switching time of FLC microlens is about 1000 times faster than that of the conventional NLC microlens which is appropriate for a fast-switching optical system.

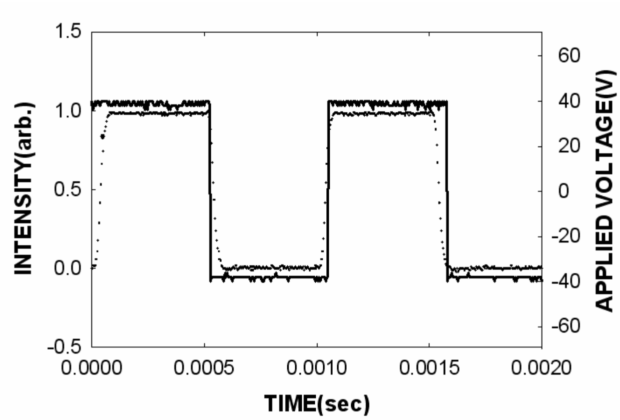



**Fig. 6. The switching time of a FLC microlens array. The solid line and dotted line represent applied voltage and light transmittance, respectively.**

## 4. Conclusion

In this paper, a new concept of microlens array is fabricated using the separate operations of the focusing and the tuning section. Compared with a conventional LC lens array, the proposed microlens array has better focusing properties, easier fabrication process, and a fast response time with good bistability. Therefore, it is hoped that this device can be used for 3D displays and optical communication systems.

## 5. Acknowledgements

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## 6. References

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