

Enhancement of the Switching Speed of a Refractive Microlens Array based on Nematic Liquid Crystals

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ABSTRACT

We demonstrated a nematic liquid crystal (NLC) microlens array with an enhanced switching speed. The NLC microlens in a vertical alignment was fabricated with reactive mesogen mixed in an alignment layer. In the NLC microlens, the switching directions of the NLC molecules were predetermined by polymerization of reactive mesogen.

1. INTRODUCTION

The liquid crystal (LC) microlens arrays (MLAs) have attracted much attention for applications to real-time optical interconnection in optical computing, three dimensional display, and photonic switching circuits due to their switchability in low voltage [1-3]. The MLAs based on the nematic LC (NLC) have been extensively reported because of the large optical anisotropy of the NLCs and their alignment capability in large area [4-6]. The refractive type of MLA having surface relief structure has some useful characteristic such as good focusing properties, dynamic changeable focal length of the MLA. Especially, a vertical alignment configuration of MLA fabricated with the NLC with negative dielectric anisotropy showed the polarization-insensitivity of the focusing properties [7]. However, the LC switching directions are not fixed due to the continuous boundary conditions at the splay-to-twist transition. Therefore, the switching time to reach a stable state is quite slow.

In this paper, we proposed a novel approach to improve switching time of a LC MLA using mixture of reactive mesogen (RM) and the alignment layer. In a vertically aligned LC MLA, the switching directions of the LC molecules were predetermined by polymerization on the substrates of the RMs. In such situation, the reorientation time of the LC directors during the splay-to-twist transition was remarkably improved.

2. EXPERIMENTAL

For fabricating the LC MLA, we fabricated the surface relief structure. The lens surface on the indium-tin-oxide (ITO) substrate was prepared with the spin-coated the UV curable polymer (NOA60, Norland). The coated substrate was irradiated by UV lamp ($\lambda = 365$ nm) under a photomask. The diameter

and the pitch of the designed photomask are 100 μm and 200 μm , respectively. Due to the modulation of UV intensity by the photomask, the monomers of UV curable polymer are diffused from blocked region to unblocked one to maintain relative density of them. For a complete polymerization of the residual monomers, the the substrate with a lens structure was irradiated by UV lamp for some minutes.

To enhance a switching speed of the NLC MLAs, the ITO substrates with the lens structure and without the structure were spin-coated with a homeotropic alignment layer mixed with RM. The AL1H659 (JSR) and the RM257 (Merck) were used for the homeotropic alignment layer and the RM, respectively. The alignment layer was pre-baked at 100 $^{\circ}\text{C}$ for 10 minute followed by curing at 180 $^{\circ}\text{C}$ for 1 hour. The LC was dropped on the lens surface and the both substrates were assembled. The LC material ($\Delta\epsilon = -3.9$, $\Delta n = 0.171$, Merck) was used in this work. The cell thickness from the edge of the lens was maintained with glass spacers of 3 μm . All

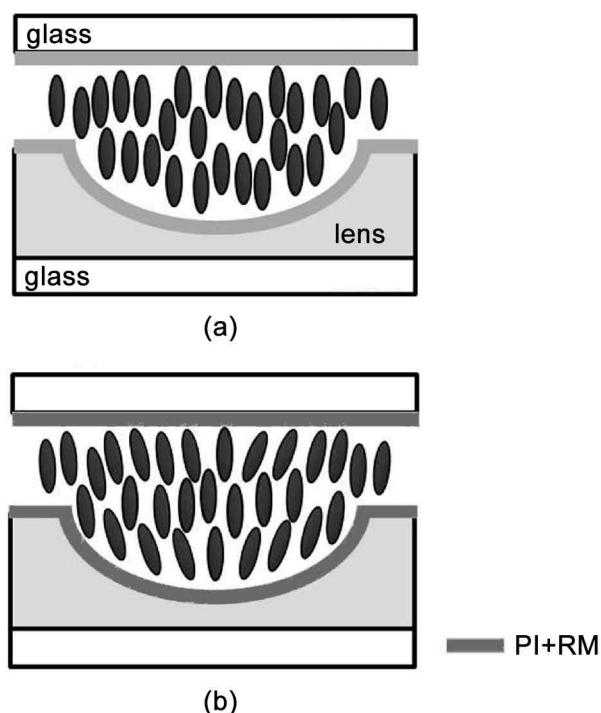


Figure 1 The schematic diagrams of (a) the conventional MLA fabricated with the pure alignment layer and (b) the proposed MLA with the mixed alignment layer.

measurements were carried out at room temperature.

3. RESULT AND DISCUSSION

Figure 1 shows the schematic diagrams of the conventional MLA fabricated with the only alignment layer and the proposed MLA with the mixed alignment layer. At the initial state, the LC molecules are aligned vertically to the substrates in both MLAs. When a voltage was applied, the LC directors were rotated with axial symmetry within the lens structure and reoriented into a spiral configuration to minimizing the deformation energy. In the conventional MLA in vertical alignment, the spiral directions were random in each lens due to the symmetric boundary condition during the voltage switching. In the proposed MLA, however, the spiral directions were always fixed even switching the voltage because the polymerized RM in the PI memorized the spiral directions in each lens. Therefore, the switching time is remarkably reduced by the reduction of the transition time from splay to twist deformations. To predetermine the spiral direction, we irradiated to lens substrate by UV lamp with applied voltage above the threshold voltage. The opposite substrate was also irradiated by UV lamp with the same voltage to polymerize residual RM monomers. As a result, the preference of the spiral deformation was determined by the polymerization of the RM.

Figure 2 shows the switching textures of the MLAs under crossed polarizers. In the absence of the applied voltage, the dark states were obtained under crossed polarizers in both MLAs since the LC

molecules were aligned vertically. In such situation, the effective refractive index of the LC is the ordinary refractive index of the NLC ($n_o = 1.5024$) and that of the UV curable polymer with lens structure is 1.56 ($n_p = 1.56$). When the voltage was applied, the LC molecules with negative dielectric anisotropy were rotated and reoriented into forming the spiral configurations. In such case, the effective refractive index in the LC exceeds that of the UV polymer, n_p , and thus the incident light is focused. As shown in Fig. 2, the spiral configurations in the conventional MLA were changed as switching the voltage, whereas in the our MLA were fixed even switching the voltage due to the memorizing effect of the RMs [8,9].

The time-resolved textures of the both MLAs at the applied voltage of 20 V are shown in Fig. 3. In the conventional MLA as shown in Fig. 3(a), when the high voltage was applied, the LC molecules with negative dielectric anisotropy were randomly rotated perpendicular to the field direction forming defects within the lens structures. After random rotation, the LC directors were reoriented to reduce the elastic deformation energy and finally minimized through formation of the spiral configuration. Therefore, the long switching time to reach the stable state (spiral configuration) was inevitably required. On the other hand, in the MLA with the RM mixed alignment layer, the LC molecules were directly rotated along the stable spiral configuration in the presence of the applied voltage as shown in Fig. 3(b). As a result, the switching speed is much faster than that of the conventional MLA because the proposed MLA has a morphological effect [10] and memorizing effect by polymerized RMs [8, 9]. As a result, the switching

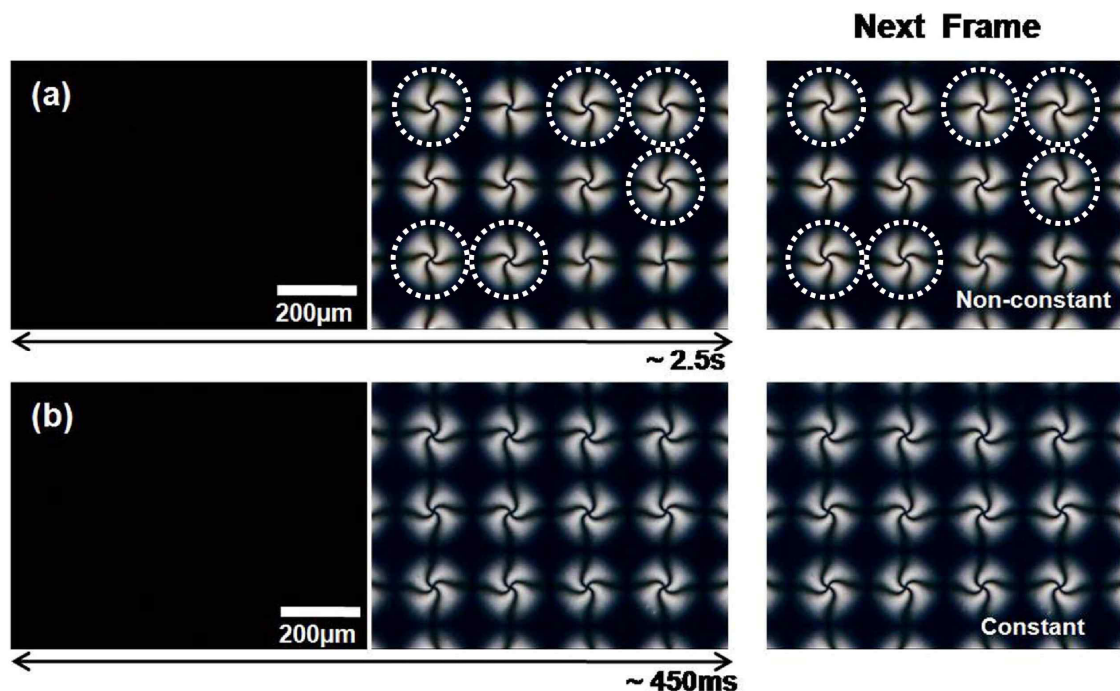


Figure 2 The switching textures of (a) the conventional MLA and (b) the proposed MLA at 8 V under crossed polarizers.

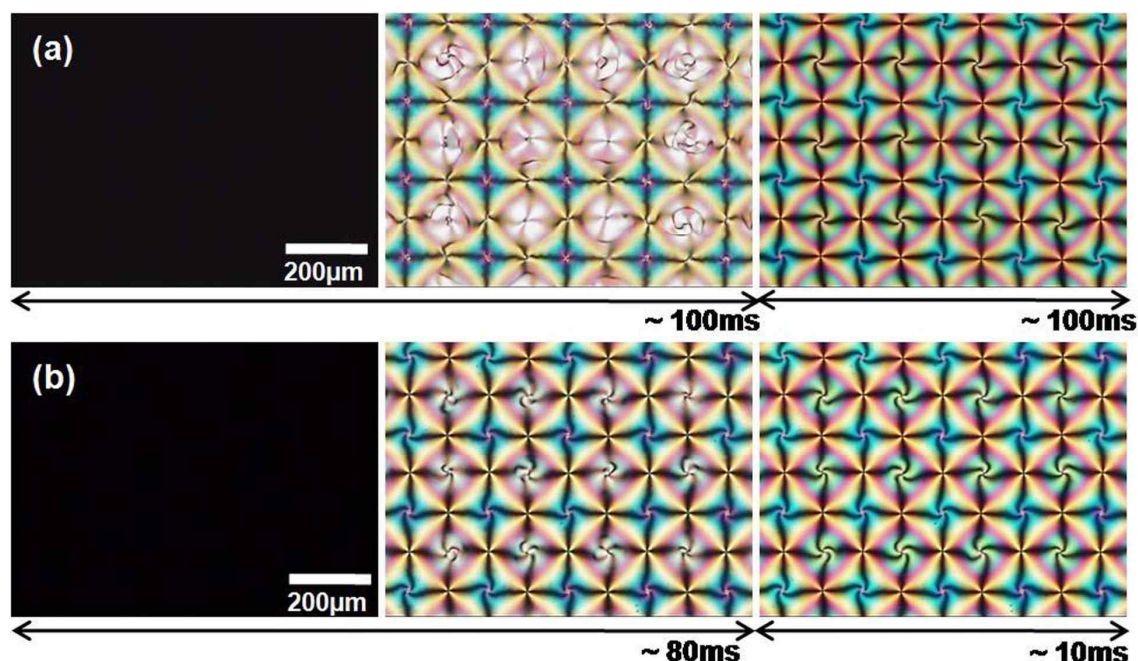


Figure 3 The time-resolved microscopic textures of (a) the conventional MLA and (b) the proposed MLA at 20 V under crossed polarizers.

speed of the LC MLA with the surface-controlled (SC) alignment layer was enhanced about 2 times more than that of the conventional MLA. The measured switching times of the conventional and the proposed MLAs at the 20 V are about 90 ms and 200 ms, respectively.

4. CONCLUSION

We demonstrated the SC MLA in a vertical alignment of the NLCs using the mixed alignment layer to improve the switching speed. The mixed alignment layer was prepared with dissolving the RM in the vertical aligning material. To polymerizing the RM monomers, UV light was exposed to the MLA under applying the voltage above the threshold voltage. The polymerized RMs produced the directional preference of the spiral deformation by breaking the symmetric boundary condition. From the time-resolved textures, the LC molecules were directly reoriented along the memorized spiral deformations in our MLA structure. As a result, the switching speed of the proposed MLA was improved about 2 times more than that of the conventional MLA.

5. ACKNOWLEDGEMENT

This research was supported by a grant (F0004121-2009-32) from Information Display R&D Center, one of the Knowledge Economy Frontier R&D Program funded by the Ministry of Knowledge Economy of Korean government and Samsung Electronics, LCD R&D Center.

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