P-118: Twisted Nematic Mode with High Contrast Ratio using Microlens Arrays

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Abstract

We propose twisted nematic (TN) mode liquid crystal device with high contrast ratio (CR) using a new microlens array (MLA) configuration composed of switching unit, focusing unit, and circular black matrix layer (BML). Consequently, CR of TN mode is improved dramatically.

1. Introduction

Several types of LCDs have been proposed under each individual merit [1-4]. Twisted nematic mode has been used widely in portable personal digital assistants and notebook computers because of its advantages, such as relatively high transmittance, low electric power consumption and simple fabrication process. Recently, TN mode also has extended drastically viewing angle which has been regarded as a weak point of it due to development of discotic film used as an optical compensation layer. However, It also has a limitation still for TV application demanding high contrast ratio (CR) due to light leakage in the dark state.

In this paper, we proposed an approach to improve dramatically CR of TN mode using MLA system for TV application. Liquid crystal lenses (LCL) have been proposed for electrically tunable focal intensity such as Fresnel type [5] a gradient refractive index (GRIN) type [6] and Polarization control type [7]. Fresnel type has been proposed to eliminate the polarization dependence due to the orthogonal alignment of the LC molecules in neighboring zones. But it requires an extremely elaborate alignment and photolithographic technique and a multi-rubbing process for practical applications. GRIN type requires also a high driving voltage and a complex fabrication. Lens property of the polarization control type is excellent, however, it can be disturb application of the optical devices due to the dependence of the polarization. Up to now, applications of such LC lenses have been defined almost in optical devices such as beam-steering, and optical interconnects. In our previous work, we proposed a dynamic MLA using the combination of lens with the liquid crystalline polymer (LCP) and LC layer [8-9]. Such dynamic lens structure has stable and enhanced dynamic focusing characteristics. In this work, we adopt that system as an optical component to improve performance of LCDs.

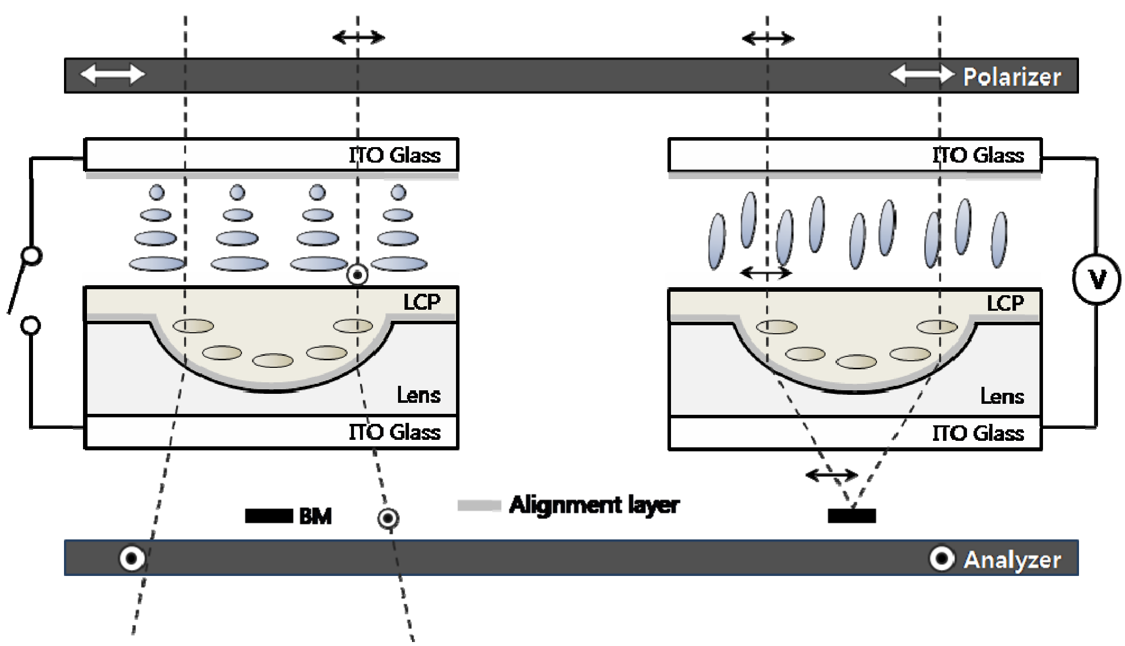

Figure 1. Schematic diagrams of the device configuration.

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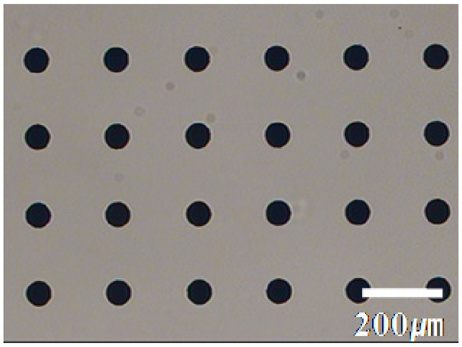
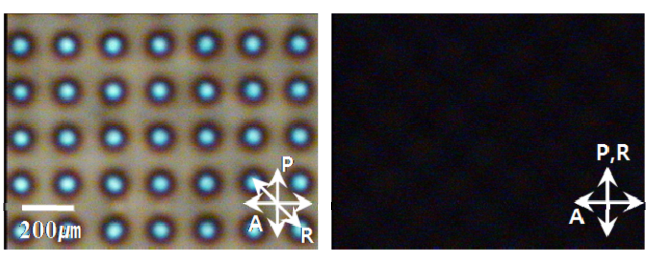


Figure 2. Black matrix fabricated by lift off method

2. Cell structure and Operation Principle

Figure 1 shows schematic diagram of the proposed optical configuration. Basic focusing mechanism is due to the refractive index difference between LCP and UV curable polymer. TN mode is able to control an incident light polarization. In the off state, the polarization of incident light becomes perpendicular to the alignment of the LCP layer by wave-guide effect in twisted LC cell. Then the refractive index of LCP is (n_o=1.525), which is the smaller than the refractive index of UV curable polymer (n_p= 1.56). So incident light diverges in the lens boundaries and the device exhibits bright state since the polarization of the light which passed through the LC layer is parallel to the optic axis of the analyzer. On the other hand, in field-on state, the incident light is focused because the effective refractive index of LCP is n_e(=1.68), which is larger than the refractive index of UV curable polymer. The focused light is first blocked by the BML, which is located to the focal point. Lights leaked in BML are blocked once more by the output polarizer. In this configuration, maximum transmittance at the bright state could be decreased slightly due to BML as compared to a general TN mode. However we can obtain dramatically advanced contrast ratio because of the improved dark state induced from double light-blocking structure of BML and polarizer.



(a) (b)

Figure 3. Microscopic texture of fabricated switching unit.

3. Experiments

MLA is composed of two crossed polarizer, TNLC-switching unit, focusing unit including LCP with large optical anisotropy, and circular type BML blocking light in the dark state.

In the TNLC-switching unit, we spin-coated the UV curable polymer (NOA60, Norland Ltd.) on indium-tin-oxide (ITO) glass. The UV curable polymer was irradiated by the collimated UV light under the patterned photo mask in first step, and without photo mask in second step to complete curing process. In the first step, the monomers of the UV curable polymer are diffused from low UV intensity region (blocked by photo-mask) to the high intensity region (unblocked by photo-mask) to preserve their balance of the concentration due to the presence of photo-mask. Consequently, MLA of surface relief structure was made clearly. The diameter and depth of the microlens are 200 μm and 7 μm, respectively. We used the commercial polyimide alignment material, RN1199 (Nissan Chemical Ind., Japan) as a layer to align LCP. The polyimide film was rubbed to obtain the correct alignment of the LCP film. And then we coated the RMS03-001(LCP) on the polyimide layer and for polymerization of RMS03-001 was irradiated by UV light (365nm) under a nitrogen atmosphere [10-11]. The LCP alignment state is shown by Figure 3.

In the switching unit, we used also RN 1199 as homogeneous LC alignment layer. Top substrate was rubbed to mutually orthogonal direction to lead to TN structure. The thickness of the LC layer was 4.5μm and LC material used TL213 (Merck) of a positive dielectric anisotropy (Δε = 5.7).

BML was fabricated by lift-off technique which is simple and easy method for patterning films. In first, we spin-coated the positive photo-resist that was irradiated by the collimated UV light under the patterned photo-mask. The irradiated part of UV light was removed by the developer. A 5000Å thick layer of

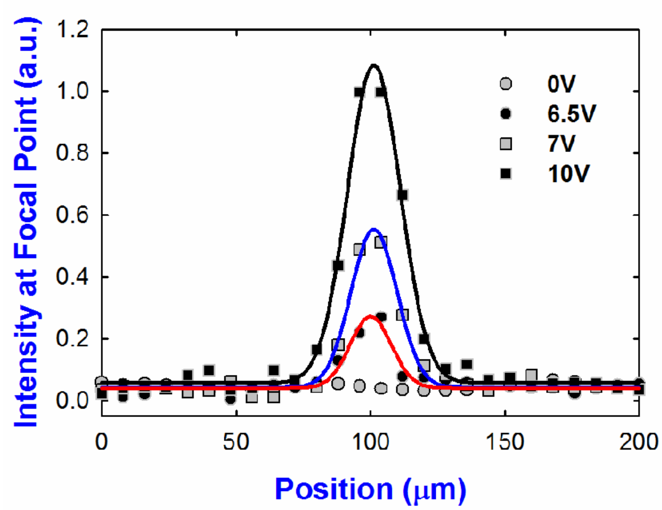


Figure 4. The intensity profile with several applied voltages

aluminum (Al) was deposited on the residual photo-resist by the evaporator. Finally, the residual photo-resist was removed by acetone and only Al pattern remains on the substrate.

The diameter and pitch of circular black matrix are 50 μm and 200 μm, respectively. Figure 2 shows the resultant black matrix pattern produced clearly by lift off technique on the substrate.

4. Results and Discussion

Under no-field, the polarization of incident light is perpendicular to the alignment of the LCP layer by polarization rotation of 90^o and then, diverges. From the result of intensity profile, the defocusing characteristic was assured. The more the voltage is gradually increased, the more polarization of incident light becomes parallel to the LCP alignment. The effective refractive index of LCP distributes from n_o to n_e. Therefore, we assure that the focal intensity gradually increases with increasing applied voltage. The focal length of MLA is 5.2 mm.

Figure 4 shows the intensity profile variations as changing applied voltage. As the applied voltage increases from 0 to 10V, the shape of intensity profile becomes sharp and Gaussian distribution.

The contrast ratio was measured using a He-Ne laser (632.8 nm). In TN cell with the BM, the maximum transmittance slightly decreased due to BM. However, the minimum transmittance decreased more greatly by double blocking of BM and polarizer. In the event, we confirmed dramatically increased CR. The CR of the TN LC cell with the BM is about two times higher than the TN LC cell.

5. Conclusion

In this paper, a new approach of high contrast TN LCD was proposed and demonstrated. The proposed TN cell is characterized by microlens array and BM. We confirmed advanced contrast ratio of the proposed TN cell from the experiment result.

6. Acknowledgements

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7. References

[1] H. L. Ong "Optical properties of general twisted nematic liquid-crystal display" Appl. Phys. Lett., Vol. **51**, pp. 1398-1400, (1987).

[2] M. Oh-e, and K. Kondo "Electro-optical characteristics and switching behavior of the in-plane switching mode" Appl. Phys. Lett., Vol. **67**, pp. 3895-3897 (1995).

[3] Q. Hong, T. X. Wu, X. Zhu, R. Lu, and S. –T. Wu "Extraordinarily high-contrast and wide-view liquid-crystal display" Appl. Phys. Lett., Vol. **86**, pp. 121107 (2005).

[4] S. Oka, M. Kimura, and T. Akahane " Electro-optical characteristics and switching behavior of a twisted nematic liquid crystal device based upon in-plane switching" Appl. Phys. Lett., Vol. **80**, pp. 1847-1849 (2002).

[5] D. -W. Kim, C. –J. Yu, H. –R. Kim, S.-J. Kim, and S. –D. Lee "Polarization-insensitive liquid crystal Fresnel lens of dynamic focusing in an orthogonal binary configuration", Appl. Phys. Lett., Vol. **88**, pp. 203505, (2006).

[6] M. Ye, Y. Yokoyama, and S. Sato "Liquid crystal lens prepared utilizing patterned molecular orientations on cell walls" Appl. Phys. Lett., Vol. **89**, pp. 141112 (2006).

[7] Y. Choi, H. –R. Kim, K. –H. Lee, Y. –M. Lee, and J. –H. Kim "A liquid crystalline polymer microlens array with tunable focal intensity by the polarization control of a liquid crystal layer" Appl. Phys. Lett., Vol. 91, pp. 221113, (2007)

[8] Y. Choi, K. –h. Lee, H. –R. Kim and J. –H Kim "Dynamic Focuing Microlens Array using a Liquid Crystalline Polymer and a Liquid Crystal" Proc. of SPIE, Vol. **6352**, pp. 63521H, (2006).

[9] J. –H. Kim and S. Kumar "Fabrication of Electrically controllable Microlens Array Using Liquid Crystals" J. Lightwave Technology Vol. **23**, pp. 628-632, (2005).

[10] G. Zhao and P. Mouroulis, "Diffusion model of hologram formation in dry photopolymer materials", J. Mod. Opt. Vol. **41**, pp.1929-1939, (1994).

[11] J. T. Sheridan and J. R. Lawrence "Nonlocal-response diffusion model of holographic recording in photopolymer" J. Opt. Am. Vol. **17,** pp.1108-1114, (2000)