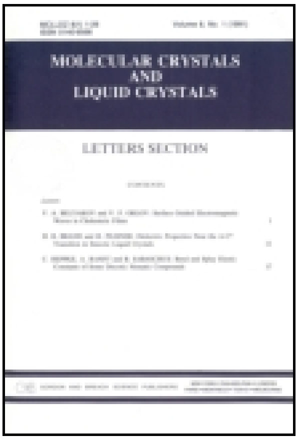

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In this article, a normally black-electrically controlled birefringence (NB-ECB) mode is presented to improve low contrast ratio of the conventional ECB mode with normally white state. It is characterized by λ/2 plate which compensates phase difference generated from liquid crystal cell at dark state. Simulated results show that the proposed NB-ECB mode can improve drastically the contrast ratio, compared with the conventional ECB mode and TN mode.

Keywords Contrast ratio; ECB mode; liquid crystal mode; normally black ECB mode

Introduction

Up to now, in order to achieve more excellent liquid crystal display (LCD), many LCD modes have been developed, such as vertical alignment (VA) type nematic modes [1,2], in-plane switching (IPS) mode [3], fringe field switching (FFS) mode [4]· twisted nematic (TN) mode [5–7], and electrically controlled birefringence (ECB) mode [8–9].

Among these, the 90° twisted nematic (TN) liquid crystal (LCD) optical mode has many merits [5–7] such as simple manufacturing process and high light efficiency. So it has been widely used in various display applications. However, it also has many demerits such as poor viewing angle characteristics and gray inversion problem. So it has been hardly used in the field of televisions, particularly large size, and high display performance display. Furthermore, it has slow response speed due to thick LC cell gap which is required to obtain high transmittance. The response time of the conventional ECB mode is faster than that of TN mode because for cell gaps showing maximum transmittance, ECB mode has smaller cell gap. However, contrast ratio (CR) of the general ECB mode is not good since light leakage occurs from surface LCs which do not move nearly along to field direction under

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field-on state of LC cell. Consequently, attempts to improve these problems of the TN mode and the ECB mode are needed seriously to create a new advanced LCD mode.

In this paper, to improve optically low CR of the conventional ECB mode and the grey inversion at side view of the conventional TN mode, a NB-ECB mode is proposed. The proposed ECB mode is characterized by $\lambda/2$ plate that compensates the phase difference in normal direction driven from LC cell. Thus, the $\lambda/2$ compensation plate is needed to obtain normally black mode. To confirm it, the electro-optic characteristics of the NB-ECB mode is compared with the conventional ECB mode and the conventional TN mode through the calculated results of contrast ratio, viewing angle, and grey level at side view.

Simulation

In order to examine the optical characteristics of the proposed NB-ECB LC structure, we used a commercial LCD simulator, TechWiz LCD, which has been developed to analyze numerically the optical characteristics of thin film transistor LCDs. LC material used at simulation is ZLI-4792 which has $\Delta n = 0.0969$. Thus the thickness of the proposed NB-ECB LC cell was 3.2 μm for maximum transmittance. As comparative cells, the cell gaps of the conventional ECB mode and the conventional TN mode are 2.8 μm and 4.5 μm, respectively as maximum transmittance conditions. The simulation was based on 560 nm wavelength. The voltages are applied to electrode from 0 V to 10 V at 0.1 V step.

Experimental

Cell Structure

Figure 1 shows simple schematic of pixel structure of the proposed LCD mode. LC layer and $\lambda/2$ compensation plate between crossed polarizers play a conclusive role optically as retardation layers. In normal state, linearly polarized light of 0° direction by the bottom polarizer becomes linearly polarized light of 90° by $\lambda/2$ plate having the optic axis of 45°. The light returns to perfectly original linearly polarized light of 0° after passing through the LC layer with the optic axis of 135°. So the state becomes perfect dark. After the LCs stand up to electric field by applied voltage, the LC layer does not carry out any role and then linearly polarized light of 90° by $\lambda/2$ plate comes out from the top polarizer. So, proposed LCD mode is achieved very bright state simply at field-on state.

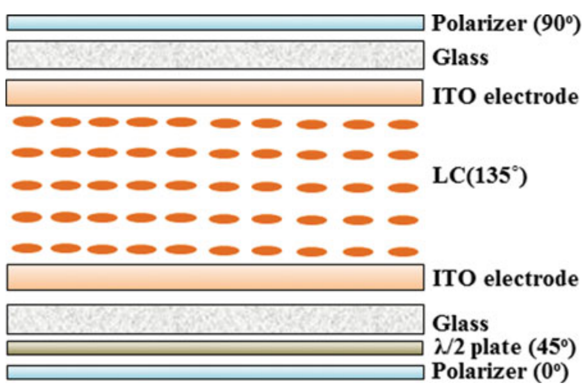

Figure 1. Schematic diagram for optical structure of the proposed NB-ECB mode.

The LC material used in this experimental is ZLI-4792(Merck) which has $\Delta n = 0.0969$ and $\Delta\epsilon$=5.2. Here, Δn and $\Delta\epsilon$ are the birefringence and the anisotropic dielectric constant of LC, respectively. The cell thickness calculated by $\Delta nd = \lambda/2$ is 2.9 μm but by considering the surface LCs which do not move along to electric field direction, it was designed to 3.2 μm. AL3046 (Nissan Chemical) polyimide was used for the LC alignment, producing a pretilt angle of 3° after a rubbing process. The λ/2 film and the polarizers were attached well on both glasses, setting their optic axes based on the optical principle. An He–Ne laser of wavelength 632:8 nm was used as the light source, and a voltage with a 1 kHz square wave of varying amplitude was applied to the electrodes.

Results and Discussion

Figure 2 shows the voltage vs transmittance curves of the conventional normally white ECB mode, TN mode, and the proposed NB-ECB mode. As seen, the conventional normally white ECB mode shows the character of light leakage even at high voltage. It is due to residual retardation by surface LCs that do not move nearly even under high electric field. The TN mode shows good dark characteristics at field-on state even though it is normally white mode, since the azimuthal directions of the surface LCs at the top and the bottom boundaries are coincident with the optic axes of the two polarizer. On the other hand, the proposed NB-ECB mode exhibits nearly perfect dark state in normal direction by optical phase compensation between the LC layer and the λ/2 plate. The contrast ratio of the conventional ECB mode is about 30: 1 at 10 V level. On the other hand, the TN mode and the proposed NB-ECB mode indicates very high contrast ratio due to good dark state. The contrast ratios of the conventional 90° TN mode and the proposed NB-ECB mode are about 500 : 1 and about 2000 : 1, respectively at level of 10 V. As a result, simulated results show that the proposed NB-ECB mode can improve drastically the contrast ratio, compared with the conventional normally white ECB mode and the conventional TN mode. Furthermore, we know that the proposed mode has very high transmittance like the conventional TN mode.

Figure 3 shows the viewing angle of each mode. The viewing angle of the conventional ECB mode shows asymmetric characteristics of the contrast ratio with respect to viewing direction, due to the severe light leakage at a specific side view of dark state under field-on.

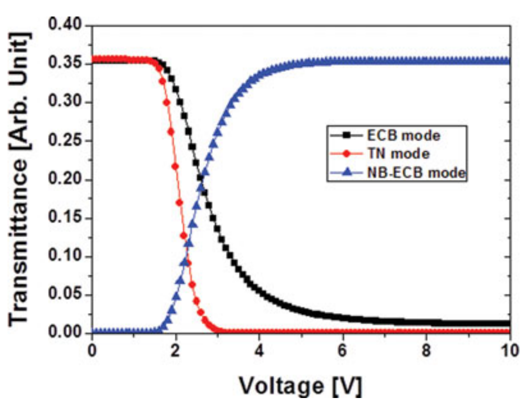

Figure 2. Simulated voltage-transmittance curves of the conventional ECB mode, the conventional TN mode, and the proposed NB-ECB mode.

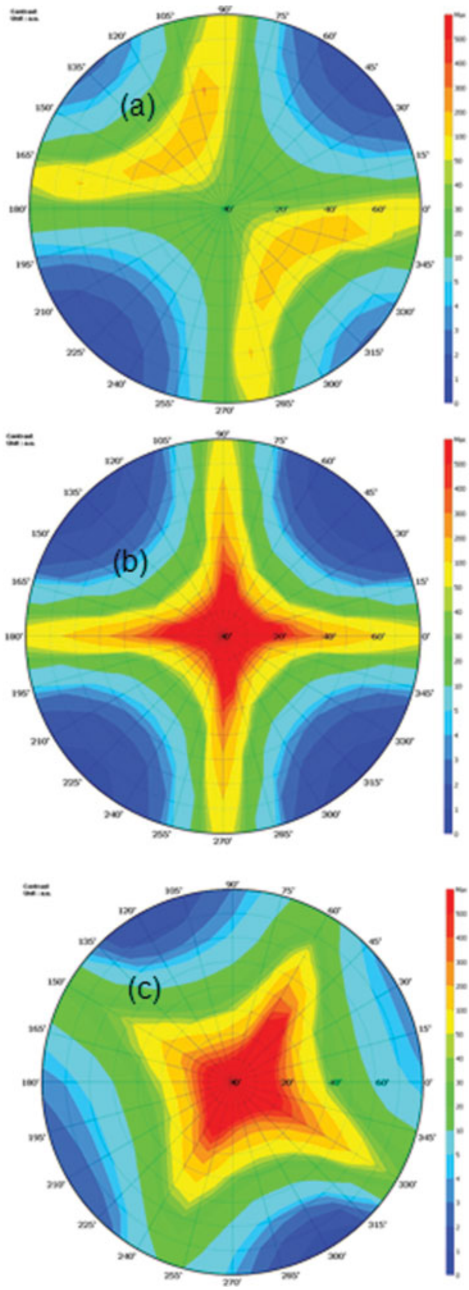

Figure 3. Viewing angle characteristics of the conventional ECB mode, the conventional TN mode, and the proposed NB-ECB mode.

The conventional 90° TN mode exhibits good symmetry of the contrast ratio with respect to viewing direction but viewing angle is narrow, which is due to the light leakage at all side views. On the other hand, we know the proposed NB-ECB mode has wider viewing angle characteristics as well as good symmetry of the contrast ratio with respect to viewing

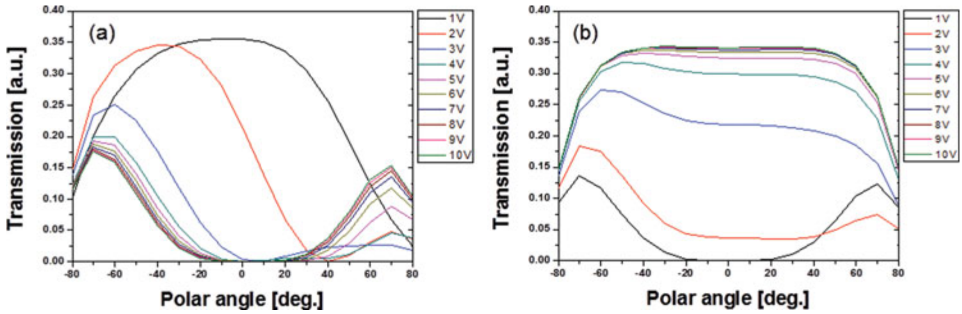

Figure 4. Grey characteristics of the conventional TN mode (a) and the proposed NB-ECB mode (b) at azimuthally 45° direction.

direction since the dark state of NB- ECB mode is achieved at LCs lying under field-off state.

Figures 4 shows the gray levels according to viewing angle of polar direction at azimuthal angle of 45° of the conventional TN mode and the proposed NB-ECB mode. As seen, the conventional TN mode has gray inversion at over polar angle of 30° due to twisted LC state as shown in Fig. 4 (a). However, in case of the NB-ECB mode, gray inversions do not appear nearly for all polar angles as shown in Fig. 4 (b) even though there is some grey inversion at 45° of 2 V.

Figure 5 shows the measured transmittance as a function of the applied voltage in the NB-ECB sample. As expected in the simulation results, the experimental result showed obvious dark and bright states at field-off (0 V) and field-on (6 V), respectively. Accordingly, it was confirmed that its electro-optical characteristics of the proposed NB-ECB mode were excellent. So we believe that this proposed NB-ECB mode with an easy fabrication process is applicable to the LCD industry. However, there remain some issues in the proposed NB-ECB LCD. Firstly, the compensation film similar to the dispersion property of LC should be developed inevitably. In addition, it does not still have sufficient viewing angle to apply it to large size panels. Therefore it requires optical design to obtain wider viewing angle using phase compensation films. Consequently, if the film is developed similarly to

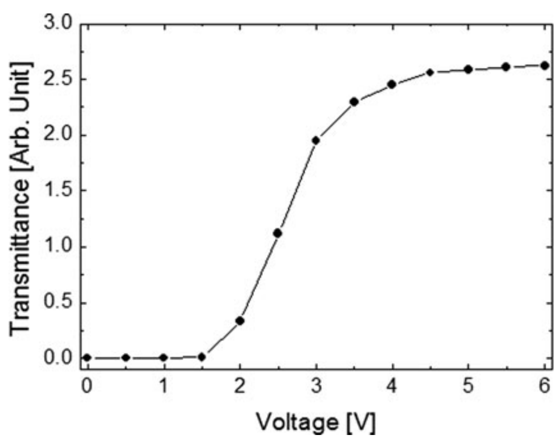

Figure 5. Measured voltage-transmittance curves of the proposed NB-ECB mode.

dispersion characteristics of target LCs, we expect that the TN mode will be substituted by our proposed mode in industry.

Conclusions

We examined a normally black-electrically controlled birefringence (NB-ECB) mode built up by $\lambda/2$ plate to improve low contrast ratio of normally white ECB mode. Simulated results shows drastic improvement of low contrast ratio in normally white ECB mode and considerable improvement of the grey inversion driven by twisted state in TN mode. Therefore, we expect that the conventional TN mode will be substituted by our proposed mode in industry.

Acknowledgments

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