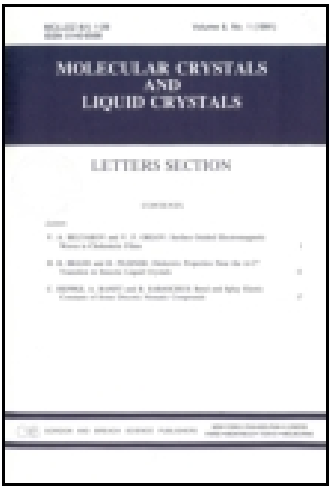

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Electro-Optical Characteristic of Two Domain Normally Black Electrically Controlled Birefringence Mode with Patterned Electrode Structure

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Electro-Optical Characteristic of Two Domain Normally Black Electrically Controlled Birefringence Mode with Patterned Electrode Structure

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We present a normally black patterned electrically controlled birefringence [NB-PECB] mode with patterned electrode structure to improve the low contrast ratio of the general electrically controlled birefringence [ECB] mode and the gray inversion of twist nematic mode [TN]. The electrode structure used in the patterned vertical alignment [PVA] electro-optic mode is adopted in our proposed NB-PECB mode to produce two domains that are required for improving viewing angle uniformity. A λ/2 plate is also used to generate normally black state. Simulated results show the proposed mode can improve the gray inversion and the contrast ratio, compared with the two domain TN mode and the two domain ECB mode.

Keywords Liquid crystal mode; normally black ECB mode; patterned electrode; contrast ratio; two domain

Introduction

A variety of TFT-liquid crystal displays (LCDs) have been competitively developed for various display applications, including television (TV) application with wide viewing angle and fast response speed. LCD modes are classified by the primary LC alignment and electrode structure which affect the direction of electric field in a pixel as vertical alignment (VA) type nematic mode [1], in-plane switching (IPS) mode [2, 3], twisted nematic mode (TN) [4, 5, 6], etc [7–13]. Among the several proposed LCD modes, TN electro-optical mode has many advantages [14, 15] such as simple manufacturing process and high light efficiency. So it has been widely used in various display applications [9]. However, it also has many weaknesses such as poor viewing angle characteristics and gray inversion. So it has been never used in the large size displays like TV. In addition, it has slow response speed due to thick LC cell gap required to obtain high transmittance[17].

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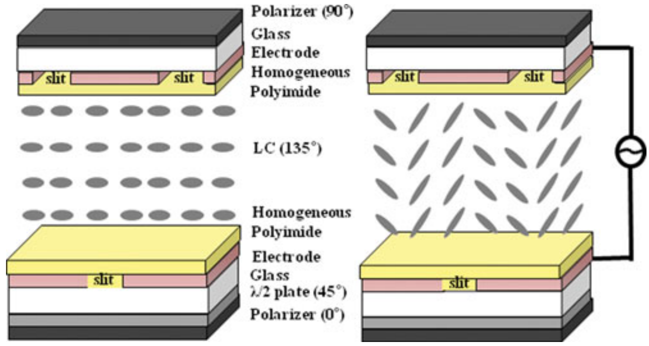

Figure 1. Cell structure of the proposed Patterned NB-ECB mode.

For electrically controlled birefringence (ECB) mode, electrode structure of it is very simple because patterning process of electrode is not needed [18]. In addition, the response time of the ECB mode is faster than TN mode because ECB mode has smaller cell gap. However, contrast ratio of ECB mode is not good since light leakage occurs due to the retardation effect of surface LCs which do not move through the electric field [19]. To solve these problems, we have proposed one domain normally black ECB mode [20]. However, it is not enough to get an uniform gray at viewing angle due to one domain which produces asymmetric LC configuration.

In this paper, we propose a new type ECB mode characterized by λ/2 compensation plate and slit electrode structure used in the electrode structure of the patterned vertical alignment [PVA] electro-optic mode. Here, the slit type-patterned electrode is adopted for generating two domains which produces symmetric LC configuration and the λ/2 compensation plate is used to obtain normally black mode that initial optical state under no-field becomes dark. We call the proposed LC mode, normally black patterned ECB mode (NB-PECB).

Cell Structure

Figure 1 shows schematic of pixel structure of the proposed mode. The slits between electrodes contribute to creating two LC domains by generating two directions of electric field at the slit boundaries. Such multi-domain structure can drive a symmetric viewing angle. LC layer and λ/2 compensation plate between two crossed polarizers play optically a crucial role as retardation layers. In initial state, linear polarized light of 0° direction by the bottom polarizer becomes linearly polarized light of 90° by λ /2 plate which has the optic axis of 45°. The light returns to perfectly original linearly polarized state of 0° after passing through the LC layer with the optic axis of 135°. So the initial optical state becomes perfect dark. After the LCs stand up with depending on electric field by applied voltage, the LC layer does not carry out any role and then linearly polarized light of 90° by λ/2 plate passes through the top polarizer. So very bright state can be performed simply.

The LC material used in this simulation 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 taking into account the surface LCs which do not move along to electric field direction, it was designed to 3.2 μm. The λ/2 film and the polarizers were attached well on both glasses with setting their optics axes based on the optical principle. As comparative cells, the cell

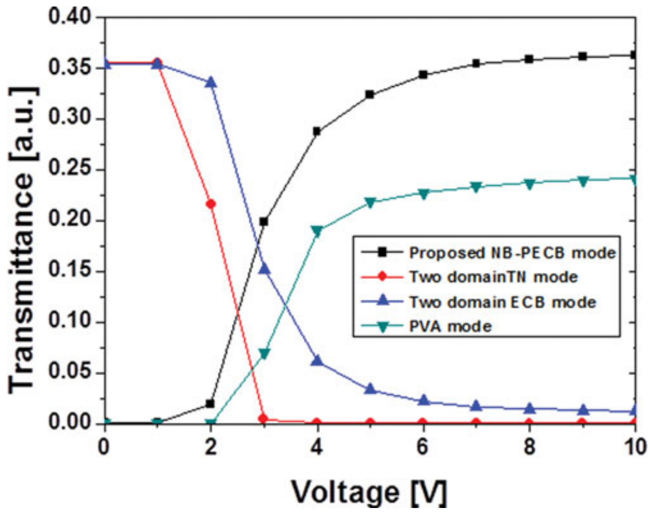

Figure 2. V-T curves of the NB-PECB mode with slit electrode structure of 10 μm : 30 μm, the two domain NW-ECB mode and the two domain TN mode.

gaps of the two domain ECB mode and the two domain 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.

Results and Discussion

Figure 2 shows the distinction of voltage-transmittance curves of the NB-PECB mode, two domain normally white electrically controlled birefringence (NW-ECB) mode, and two domain TN mode. Then, the width of the slit electrode is 10 μm and the distance between the top and the bottom slits is 30 μm similar to the electrode scale of the general PVA mode. As we expected, the proposed mode has high transmittance like the conventional TN mode.

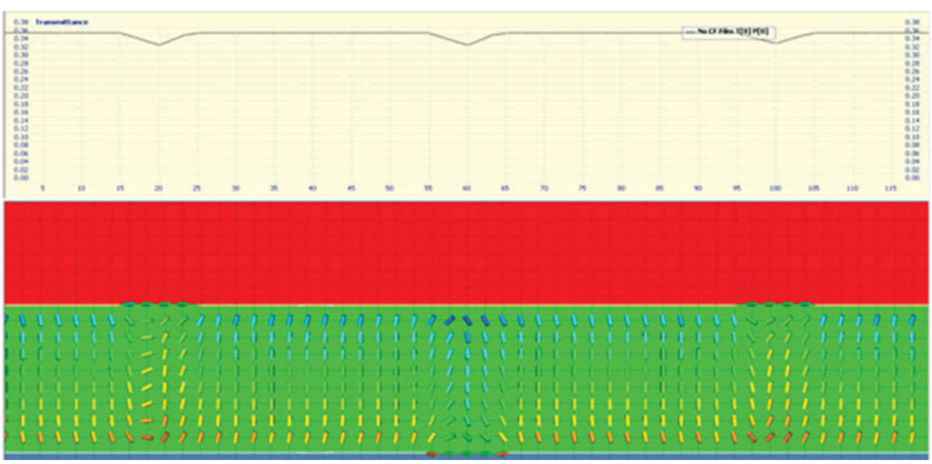

Figure 3. The transmittance and LC director profile according to the position of a pixel when 10 V is applied to the proposed NB-PECB mode.

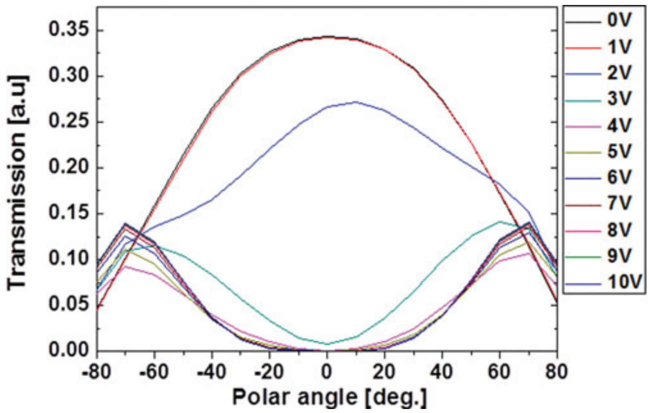

Figure 4. Gray levels according to polar viewing angle at azimuthal 45° of the two domain TN mode.

It is caused from transmission at the slits as shown in Fig. 3. In general, the slit region at the PVA mode shows very low transmission due to vertically aligned LCs which do not lie down under electric field at the slit region. On the other hand, in case of the proposed mode with horizontally aligned LCs, we can know that LCs rise up by electric field at the slit region. Thus, the proposed NB-PECB mode exhibits high transmittance. And the proposed NB-PECB mode shows very good darkness which generates very high contrast ratio due to the retardation compensation by $\lambda/2$ plate. As a result of the simulation, the contrast ratios of the two domain ECB mode and the two domain TN mode, and the proposed NB-PECB mode are about 28 : 1, about 450 : 1, and about 1800 : 1, respectively at level of 10 V. As a result, simulated results show that the proposed NB-PECB mode can improve drastically the contrast ratio, instead of the conventional ECB mode and the conventional TN mode. Furthermore, the transmittance of the proposed mode is nearly as high as the conventional TN mode.

Figures 4 and 5 show the gray levels according to viewing angle of polar direction at azimuthal angle of 45° for the two domain TN mode and the NB-PECB mode, respectively.

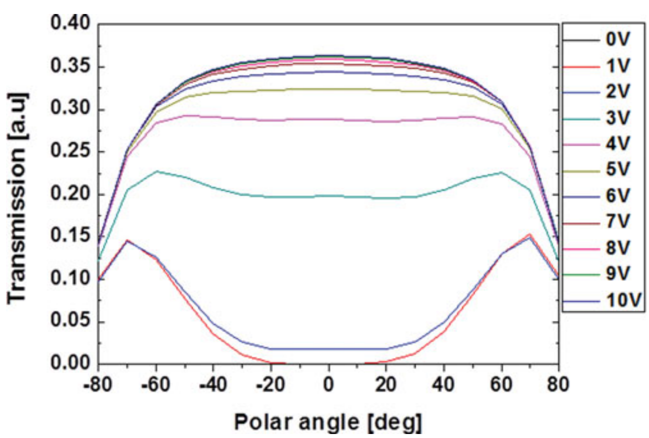

Figure 5. Gray levels according to polar viewing angle at azimuthal 45° of the proposed NB-PECB mode.

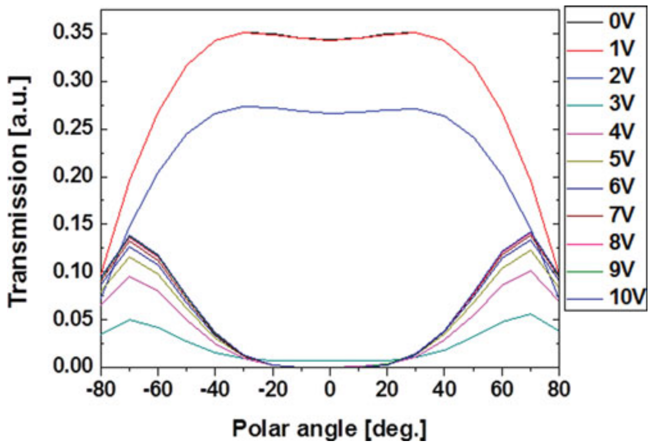

Figure 6. Gray levels according to polar viewing angle at azimuthal 135° of the two domain TN mode.

As seen, the TN mode has gray inversion from polar angle of 45°. The gray inversion characteristics of the TN mode is caused by the twisted structure of LCs. On the other hand the gray inversion at NB-PECB mode which does not produce the twisted LC structure does almost not appear and the gray levels is symmetric with respect to the polar angle of 0° due to two domain structure.

Figures 6 and 7 show the gray levels according to viewing angle of polar direction at azimuthal angle of 135° for the two domain TN mode and the NB-PECB mode, respectively. As seen, the TN mode has gray inversion from polar angle of 30°. It also is produce from the twisted LC structure of the TN mode. However the gray inversion at NB-PECB mode which does not drive the twisted LC structure does almost not appear and the gray levels is also symmetric with respect to the polar angle of 0° due to two domain structure. As

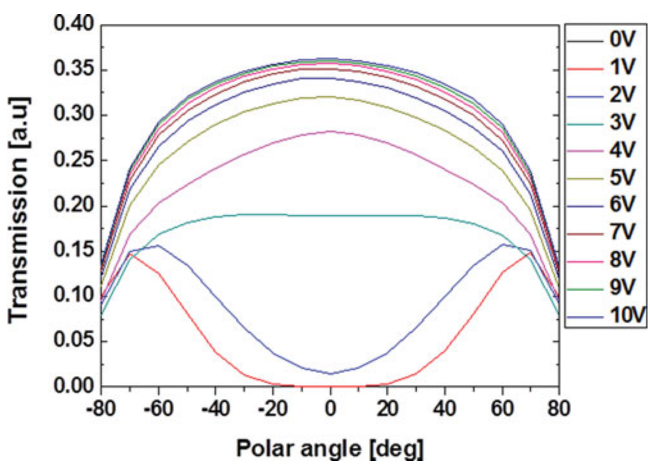

Figure 7. Gray levels according to polar viewing angle at azimuthal 135° of the proposed NB-PECB mode.

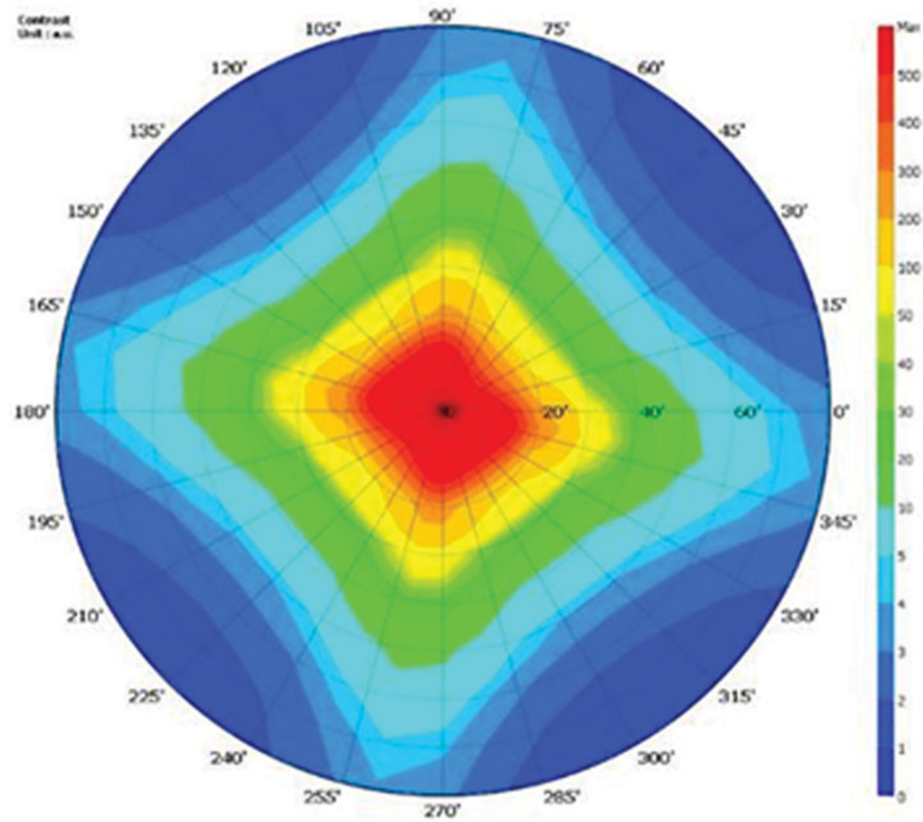

Figure 8. Contrast contour in viewing angle of the NB-PECB mode.

the result of the gray inversion simulation, the NB-PECB mode has more excellent gray characteristics than it of the conventional two domain TN mode.

Lastly, in order to examine the optical characteristics at side view of the NB-PECB mode with good darkness, we calculate the contrast ratio at viewing angle of it. Figure 8 shows contrast contour in viewing angle of the NB-PECB mode. As expected, it depicts very symmetrical viewing angle characteristics produced from two domain LC structure. In general, the optical characteristics with such a symmetrical viewing angle can be extended for wide viewing angle by using two uniaxial compensation films or biaxial compensation film.

Consequently, the simulated results show that the proposed NB-PECB mode has better image quality than the two domain ECB mode and the two domain TN mode. We expect that the NB-PECB mode will be used in industry instead of the TN mode.

Conclusions

We studied on a normally black patterned electrically controlled birefringence (NB-PECB) mode built up with $\lambda/2$ plate and slit electrode structure used in the PVA mode to improve a low contrast ratio of normally white ECB mode and a gray inversion of twist nematic (TN) mode. The results show that issues for the contrast ratio and the gray inversion at

NW-ECB mode and TN mode can be improved by the proposed NB-PECB mode. So if a compensation film nearly similar to optical properties of LC is developed so that the optical phase difference generated from LC layer may be compensated completely, we expect that the TN mode will be replaced by our proposed mode in industry.

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