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Analysis of operation mode of reflective twisted nematic liquid crystal display devices with rear film compensation

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The rear film compensated reflective twisted nematic liquid crystal display device was studied in normally black and normally white operation conditions using a dynamic parameter space method. The electro-optical responses and reflectance spectra were also studied for different operation modes. A comparison was made between rear film and front film compensated reflective twisted nematic liquid crystal displays. We show that high quality normally white or normally black modes can be obtained by placing the fast axis of a quarter wave plate at 45° or 0° to the input director direction. The viewing angle characteristics of the optimum modes were also studied.

1. Introduction

Research interest has been growing recently in the study of reflective liquid crystal displays (LCDs) [1–4]. Reflective LCDs can be classified into two categories depending on whether the display uses polarizers or not. Reflective cholesteric displays and absorptive guest–host displays do not use polarizers; reflective nematic LCDs do use polarizers. Reflective nematic LCDs are displays based on polarization manipulation, as in conventional twisted nematic LCDs. However, unlike conventional LCDs, there is only one front polarizer and the rear polarizer is eliminated. The single polarizer configuration reduces light loss and is preferred in the reflective LCDs. The main applications for such reflective LCDs are in direct view displays such as mobile telephones and personal digital assistance. Reflective nematic LCDs can be further divided into two categories depending on the LCDs having twist angles. Reflective LCDs having no twist are the parallel-aligned homogeneous cell, the homeotropic cell and the hybrid-aligned nematic (HAN) cell. Those displays rely on a pure electrically controlled birefringence (ECB) effect. Reflective LCDs with twist rely on a combination of the waveguiding twisted nematic (TN) and ECB effects.

In previous studies, we analysed operation modes of reflective twisted nematic LCDs without compensation [5]. We also analysed the operation modes of reflective twisted nematic LCDs with front compensation [6]. In this article, we will study the reflective twisted nematic LCDs with rear compensation (quarter wave plate placed between the liquid crystal cell and the mirror reflector) as illustrated in figure 1. Although parallax may exist in the rear compensation configuration, it could be minimized by reducing the substrate thickness. In fact, for conventional two polarizer reflective LCD devices, the diffuse reflector is placed between the substrate glass and the rear polarizer. From the point of view of analysis of reflective twisted nematic display devices, it it interesting to compare the results of a reflective twisted nematic LCD device with rear compensation or with front compensation.

A systematic computer simulation of reflective liquid crystal display devices with rear compensation will be given in terms of the dynamic parameter space method [7]. The parameters defining the parameter space are the thickness and birefringence product $d\Delta n$, the liquid crystal twist angle ϕ and the angle between polarizer and input director β. These three parameters basically determine the optical properties of liquid crystal devices. The liquid crystal material parameters K_{11}, K_{22}, K_{33}, $\varepsilon_{\perp}$ and $\varepsilon_{\parallel}$ are closely related to the dynamic response, so they are not included in the parameter space. The dynamic parameter space method essentially consists of a series of transmission or reflectance contour plots

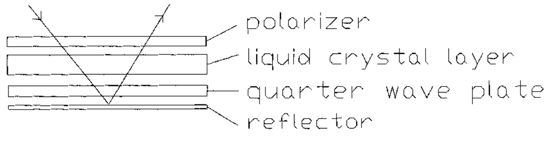

Figure 1. Illustration of the reflective liquid crystal display device with rear compensation.

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in $\{\varphi, d\Delta n, \beta\}$ space with one parameters fixed when a varying voltage is applied. This method is based upon very efficient programming for the calculation of director profile by the variation technique [8]. Berreman's 4 × 4 matrix method is used to calculate optical properties [9]. Two different types of contour plot will be shown in this paper: the reflectance contour plot and contrast ratio contour plot. This contrast ratio is simply the ratio of reflectances in the 'on' and 'off' states. The director distribution in the liquid crystal cell is calculated for the entire range of twisted angle ϕ from 0° to 360° at a given voltage, and reflectance is calculated for each twist angle with $d\Delta n$ ranging from 0 to 2.5 µm.

2. Normally white mode

A simple geometry for the reflective device with rear compensation was adopted in studying the normally white mode. The input director and the polarizer were assumed to be along the same direction. Liquid crystal material parameters used in the calculation are listed as follows. $K_{11} = 12.4 \times 10^{-10}\,\mathrm{J\,cm^{-1}}$; $K_{22} = 6.0 \times 10^{-10}\,\mathrm{J\,cm^{-1}}$; $K_{33} = 17.1 \times 10^{-10}\,\mathrm{J\,cm^{-1}}$; $\varepsilon_{\perp} = 6.6$; $\varepsilon_{\parallel} = 13.8$; pretilt angle is 2°; cell thickness d is 5.0 µm. Pitch p $(= 2\pi d/\phi)$ varies with twist angle. The director profile was calculated for each twist angle from 0° to 360°; its optical property was calculated by the Berreman 4 × 4 matrix method. Assuming the reference direction to be the input director direction, positive ϕ direction means that director twists in an anti-clockwise fashion, beginning from the input director.

The quarter wave plate was also treated as a layer of anisotropic medium in the Berreman 4 × 4 matrix method, its Δnd was equal to $\lambda/4$. The angle between the fast axis of the quarter wave plate and the input director direction was 45°. The wavelength used in all calculations was 550 nm.

Figures 2 and 3 show reflectance contour plots of this reflective device in the 'off' state and the 'on' state. The voltages applied at 'off' and 'on' were 0.0 and 4.0 V, respectively. In all contour plots $d\Delta n$ is in microns. The reflectance was normalized to the reflectance of an aluminum mirror with front polarizer attached to the aluminum mirror by itself. The reflectance was normalized in the same way for all of this investigation. Figure 4 shows the contrast ratio contour plot $(R_{\mathrm{off}}/R_{\mathrm{on}})$.

Three possible operation modes from figure 4 may be discussed. They are mode A at ($\phi = 85°$, $\Delta nd = 0.20\,\mu\mathrm{m}$), mode B at ($\phi = 180°$, $\Delta nd = 0.50\,\mu\mathrm{m}$) and mode C at ($\phi = 280°$, $\Delta nd = 0.45\,\mu\mathrm{m}$). The electro-optical responses for the three modes were calculated as shown in figure 5. They show the same tendency as transmissive liquid crystal devices, in that the steepness of the electro-optical response depends mainly on the twist angle. Figure 6 shows the reflectance spectra for the modes A, B and C in the 'off' and 'on' states. The voltage applied in the 'on' state for modes A, B, and C was 2.5, 2.5 and 3.0 V, respectively. The reflectance spectra show a good dispersion property. The dependence of the contrast ratio on viewing angle is shown in figure 7 for mode B. The characteristic of the viewing angle is symmetric. The contrast ratio is greater than 3.0 within a viewing angle ± 30°.

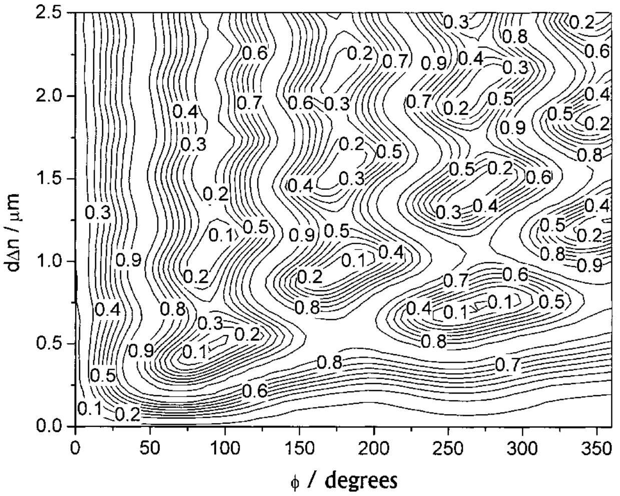

Figure 2. Reflectance contour plot for the 'off' state for the normally white mode.

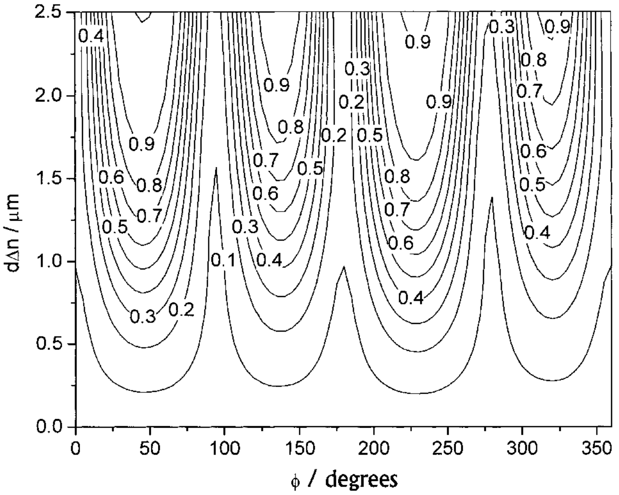

Figure 3. Reflectance contour plot for the 'on' state for the normally white mode.

3. Normally black mode

The polarizer and input director were here also assumed to be along the same direction for the analysis of normally black modes. The angle between the input direction and the quarter wave plate fast axis is 0°. The contrast ratio contour plot $(R_{\mathrm{on}}/R_{\mathrm{off}})$ is shown in figure 8. The voltage applied at the 'off' and 'on' states

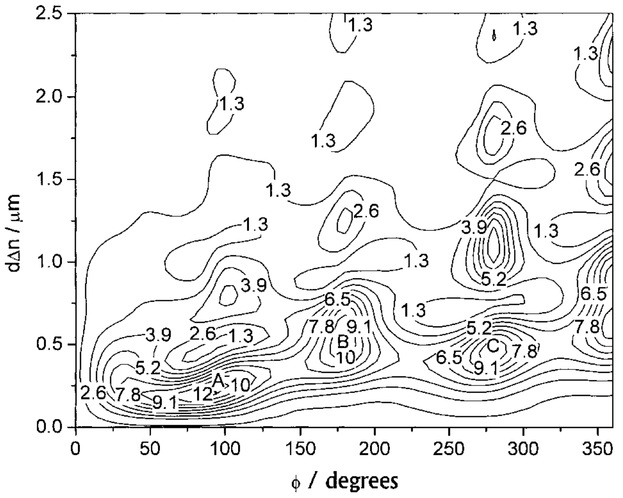

Figure 4. Contrast ratio contour plot (R_{off}/R_{on}) for the normally white mode.

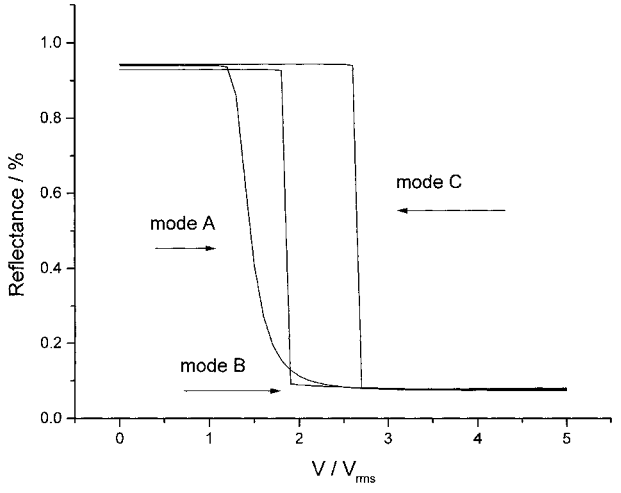

Figure 5. Electro-optical response for the normally white mode.

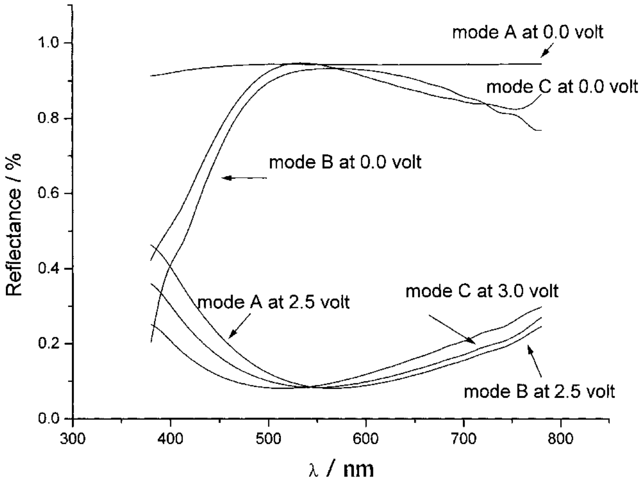

Figure 6. Reflectance spectra for modes A, B and C.

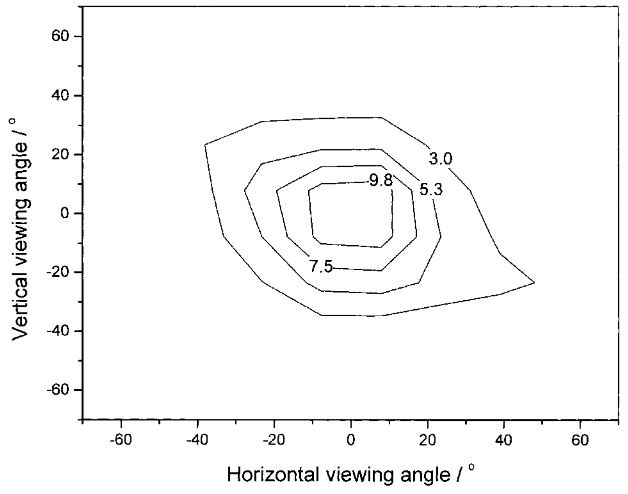

Figure 7. Viewing angle dependence of the contrast ratio for mode B.

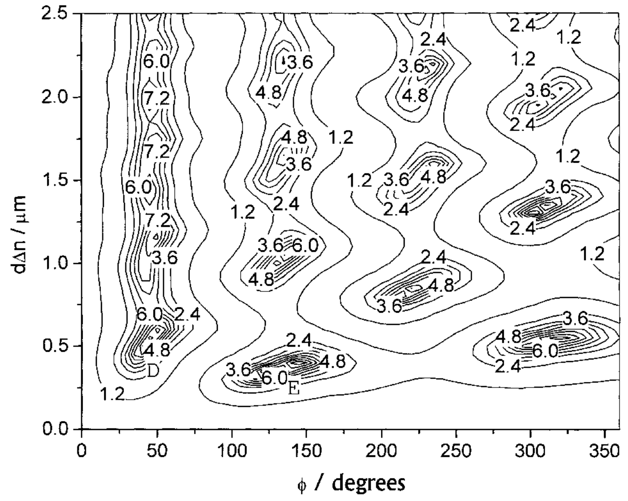

Figure 8. Contrast ratio contour plot (R_{on}/R_{off}) for the normally black mode.

was 0.0 and 4.0 V, respectively. From this figure, only mode D at ($\phi = 45°$, $\Delta nd = 0.60\,\mu m$) and mode E at ($\phi = 145°$, $\Delta nd = 0.40\,\mu m$) are discussed. They are 'first margin minima'; their electro-optical responses are shown in figure 9. Because mode E has a larger twist angle, its electro-optical response is steeper. The reflectance spectra for modes D and E are shown in figure 10. The voltage applied in the 'on' state for the two modes was 2.0 and 2.5 V, respectively. Mode D has a better dispersion property than mode E. The viewing angle dependences of the contrast ratio are shown in figures 11 and 12 for modes D and E. Mode E has a wider viewing angle characteristic, its contrast ratio is larger than 3.0 within a viewing angle of ± 50°.

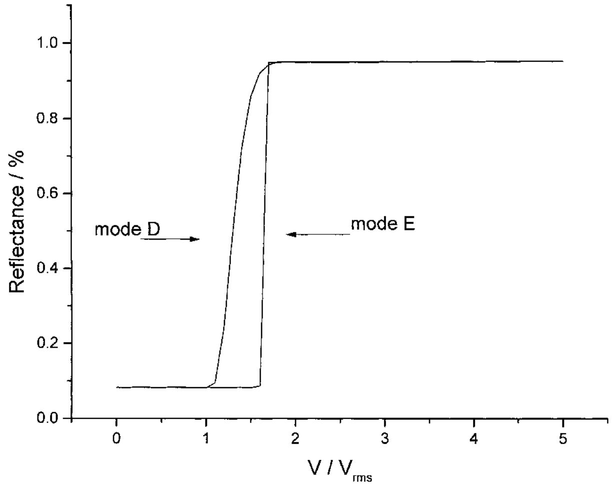

Figure 9. Electro-optical response for the normally black mode.

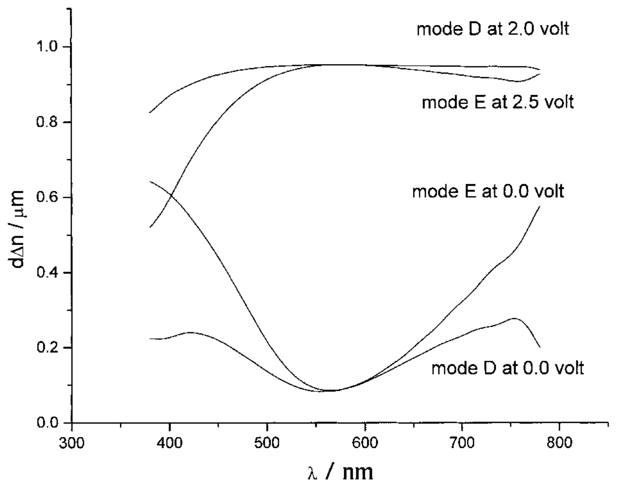

Figure 10. Reflectance spectra for modes D and E.

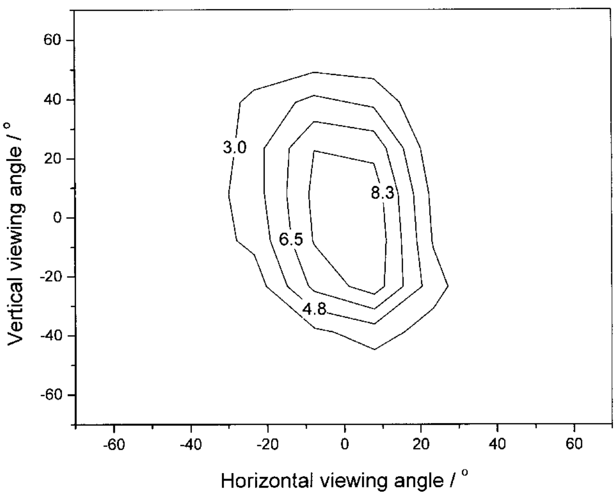

Figure 11. Viewing angle dependence of the contrast ratio for mode D.

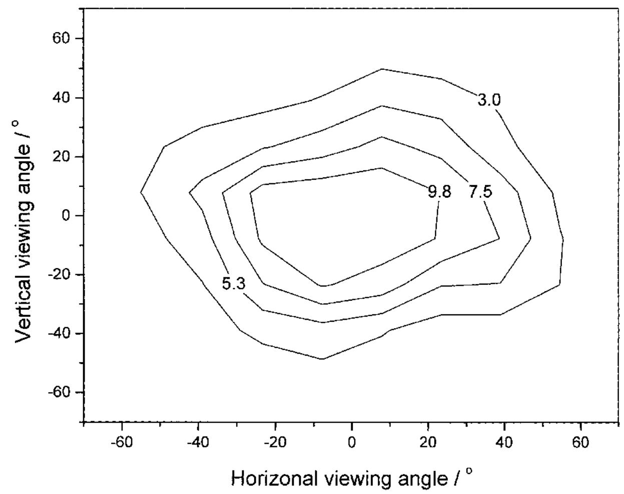

Figure 12. Viewing angle dependence of the contrast ratio for mode E.

4. Conclusions and discussion

The rear film compensated reflective twisted nematic LCD device was analysed in terms of the dynamic parameter space method. For the normally white operation, three optimum modes A at ($\phi = 85°$, $\Delta nd = 0.20\,\mu m$), B at ($\phi = 180°$, $\Delta nd = 0.50\,\mu m$) and C at ($\phi = 280°$, $\Delta nd = 0.45\,\mu m$) were found. They have good electro-optical responses and dispersion properties. The viewing angle for mode B was also shown; its contrast ratio is greater than 3.0 within a viewing angle of ± 30°. For the normally black operation, mode D at ($\phi = 45°$, $\Delta nd = 0.60\,\mu m$) and mode E at ($\phi = 145°$, $\Delta nd = 0.40\,\mu m$) were analysed for electro-optical response, reflectance spectra and viewing angle dependence of the contrast ratio. Mode E has a wide viewing angle characteristic; its contrast ratio is greater than 3.0 within a viewing angle of ± 50°.

In comparison with front film compensated reflective twisted nematic displays, rear film compensated reflective twisted nematic displays have three white operation modes. The front compensated reflective have only one normally white operation mode with twist angle 90° [6]. Rear film compensated reflective twisted nematic displays have two normally white operation modes working in the supertwisted region. These two modes can be passive matrix driven and a high multiplex ratio can be achieved. The normally black mode at ($\phi = 45°$, $\Delta nd = 0.60\,\mu m$) of the rear film compensated reflective display has a larger $d\Delta n$ value in comparison with the normally black mode at ($\phi = 60°$, $\Delta nd = 0.20\,\mu m$) of the front film compensated reflective display. The large $d\Delta n$ value will make device fabrication much easier.

To summarize, we have analysed operation modes for the reflective device with rear film compensation. The simple configuration of parallel polarizer and input director, and 45° or 0° quarter wave plate for the rear film compensated reflective device gives very good operation modes for both normally white and normally black operation.

References

[1] Sonehara, T., 1990, *Jpn. J. appl. Phys.*, **29,** L1231.

[2] Fukuda, I., Kitamura, M., and Kotani, Y., 1995, *Asia Display*, Proceedings of the 15th International Display Research Conference, Hamamatsu, Japan (Society for Information Display), p. 881.

[3] Wu, S. T., and Wu, C. S., 1996, *Appl. Phys. Lett.*, **68,** 1455.

[4] Tillin, M. D., Towler, M. J., Saynor, K. A., and Beynon, E. J., 1998, *SID Dig.*, 311.

[5] Cheng, H., Gao, H., and Zhou, F., 1999, *Liq. Cryst.*, **26,** 1573.

[6] Cheng, H., Gao, H., and Zhou, F., *Liq. Cryst.* (submitted).

[7] Cheng, H., Gao, H., and Zhou, F., 1999, *J. appl. Phys.*, **86,** 5953.

[8] Sugimura, A., Luckhurst, G. R., and Zhong-can, O.-Y., 1995, *Phys. Rev. E*, **52,** 681.

[9] Berreman, D. W., 1972, *J. opt. Soc. Am.*, **62,** 502.