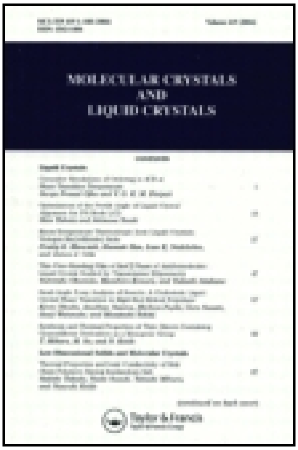

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Improved Performance of a Single-Polarizer DTN-LCD with a Retardation Film

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IMPROVED PERFORMANCE OF A SINGLE-POLARIZER DTN-LCD WITH A RETARDATION FILM

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We numerically analyzed the relationship between the electro-optical properties and the on-voltage of a TFT-LCD in a single-polarizer reflective double-layered TN-LCD (DTN-LCD) with a retardation film in order to confirm the possibility of reducing power consumption. Our results demonstrate that the LCD exhibits an achromatic image of high luminous reflectance of about 50% and very high contrast ratio, even if the on-voltage is reduced to 2 V. The power consumption can thus be decreased to about 1/6 that of the presently used reflective 5 V TFT-LCD in the on-state.

Keywords: reduced power consumption; reflective DTN-LCD; retardation film; single-polarizer

1. INTRODUCTION

Compact, portable information equipment such as notebook computers and PDAs have progressed remarkably in recent years. This has created a need for bright reflective color liquid-crystal displays (LCDs) without backlighting. Various types of reflective color LCDs have been proposed in response to this requirement [1]. We previously proposed a new, single-polarizer achromatic reflective TN-LCD [2] and STN-LCD [3,4] with one retardation film. We obtained superior luminance as well as a high contrast ratio through the optimum design of the retardation film and the device parameters. The LCDs enable a reflective color LCD that uses a color mixing system such as a micro color filter. These improved types of single-polarizer LCDs are presently being used in practical applications. However, the power consumption of the reflective color TN-LCD is several times greater than that of a color reflective STN-LCD. It would be advantageous

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to reduce the TN-LCD's power consumption while maintaining its superior image quality. We numerically analyzed the relationship between the electro-optical properties and the on-voltage of a TFT-LCD in a single-polarizer reflective double-layered TN-LCD (DTN-LCD) with a retardation film [5] in order to confirm the possibility of reducing power consumption. We found that the LCD exhibits an achromatic image of a superior luminous reflectance of about 50% and a very high contrast ratio, even if the on voltage is reduced to 2 V. The power consumption can thus de decreased to about 1/6 that of the presently used reflective 5 V TFT-LCD in the on state. An LCD that uses a double-layered TN cell has a weight disadvantage because of its four glass substrates. Thus, we also proposed a single-polarizer film TN-LCD with a retardation film, replacing the compensating TN cell in the above-mentioned DTN-LCD with a liquid crystal polymer film [5] with a twist angle and retardation of the same magnitude as the LC layer.

2. STRUCTURE

Figure 1 shows the new reflective LCD using a single-polarizer DTN-LCD with a retardation film. An LCD that uses a double-layered TN cell has a weight disadvantage because of its four glass substrates. We propose a single-polarizer film TN-LCD with a retardation film to solve this problem, replacing the compensating TN cell shown in Fig. 1 with a liquid crystal polymer film [6] with a twist angle and a retardation of the same magnitude as the LC layer shown in Figure 2.

The reflectance in a single-polarizer reflective-TN-LCD is determined only by the ellipticity of light on the reflector as shown in Figure 3 [6]. Therefore, the reflectance of the DTN-LCD that eliminates the retardation film from the LCD shown in Figure 1 becomes 50% in the off-state because the outgoing lineally polarized light from the polarizer arrives at the

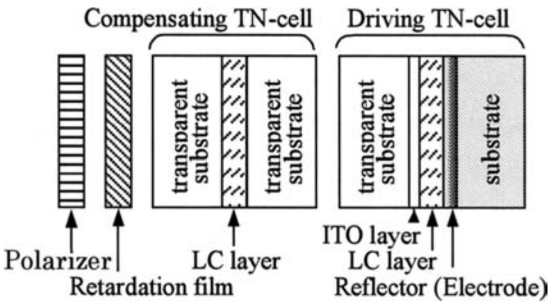

FIGURE 1 Configuration of a reflective DTN-LCD with a retardation film.

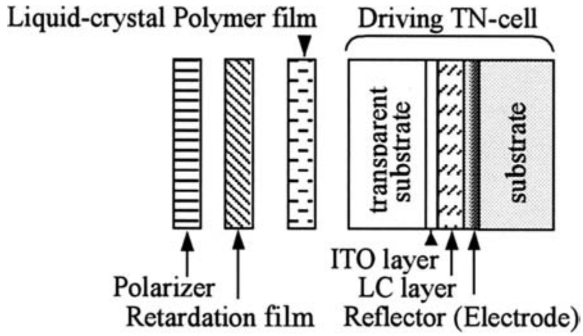

FIGURE 2 Configuration of a reflective film TN-LCD with a retardation film.

reflector unchanged, assuming that the following three conditions are satisfied simultaneously.

(1) The twist angle in the LC layer of a driving TN cell and a compensating TN cell must be the same magnitude, but in opposite directions.
(2) The retardations of the LC layer in the two TN cells must be the same magnitude.
(3) The optical axes, or the rubbing directions of the adjacent surfaces of the two TN cells must cross at right angles.

The role of the retardation film is to obtain an achromatic image of a high contrast ratio while maintaining the ideal light condition descried above in the off-state.

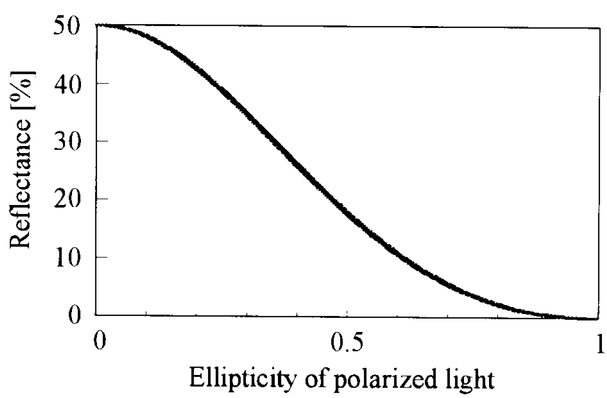

FIGURE 3 Relationship between reflectance and ellipticity of polarized light on the reflector.

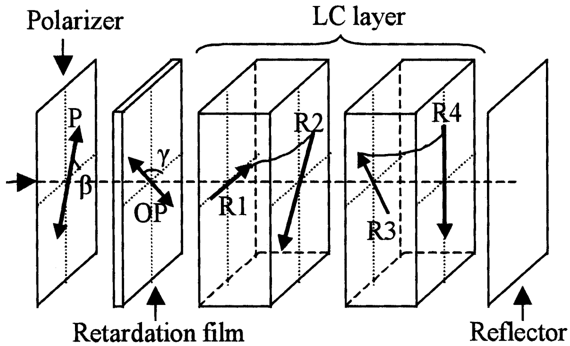

FIGURE 4 Directions of axes in a reflective DTN-LCD with a retardation film.

3. ANALYSIS

We numerically analyzed the relationship between the electro-optical properties and the on-voltage of a TFT-LCD in the reflective LCD shown in Figure 1 to confirm the possibility of obtaining a bright achromatic-image with a high contrast ratio even when the on-voltage is reduced to 2 V. To obtain the optimum cell parameters, we calculated the reflectance by using the Oseen-Frank elastic theory and the Stokes parameters and Mueller matrix. Figure 4 illustrates the directions of the axes in the DTN cell shown in Figure 1, where P is the polarization axis, OP is the optical axis of the retardation film, and R1, R2, R3 and R4 are the optical axes at the surface of the LC layer or the rubbing directions of the substrates. Table I provides the typical values of parameters used in the calculation, and Table II gives the five parameters to be optimized. In Table II, Φ is the twist angle of the LC layer, β is the directions of the polarizer, $(\Delta n \cdot d)_{LC}$ is the retardation of the compensating TN cell and/or the driving TN cell, and $(\Delta n{\cdot}d)_R$ and γ are the retardation and the direction of the retardation film, where Δn is the birefringence and d is the cell gap or film thickness. A TFT-LCD of 0 V in the off-state and 2.0 to 4.5 V in the on-state was assumed, and the

TABLE 1 Typical Values for Several Parameters Used in Calculation

Parameters		Values
Ratio of elastic constant	K_{33}/K_{11}	1.20
	K_{33}/K_{22}	2.50
Ratio of dielectric constant	$\Delta\varepsilon/\Delta\varepsilon_\perp$	1.64
Pretilt angle	θ_0 [°]	2

TABLE II Parameters to be Optimized

ϕ [°]	twist angle
$(\Delta n \cdot d)_{LC}$ [μm]	retardation of liquid crystal layer
β [°]	direction of the polarizer
$(\Delta n \cdot d)_R$ [μm]	retardation of the retardation film
γ [°]	direction of the retardation film

electro-optical properties observed from the normal direction were investigated.

4. RESULT AND DISCUSSION

Figure 5 shows the calculated relationships between γ and $(\Delta n{\cdot}d)_R$ required to obtain an achromatic image with a luminous reflectance exceeding 49% and a contrast ratio greater than 16:1 for the LCD with 63° twist and 4.5 V on-voltage. Figure 5 presents four groups of solutions that exist in the indicated range of γ and $(\Delta n{\cdot}d)_R$. We refer to the groups as A, B, C, and D. To clarify the electro-optical properties of each group, we analyzed the optimal cell parameters used to obtain the highest contrast ratio. Group A was found to have the best superior electro-optical properties for a color display with a micro color filter because of the lowest dependence of the reflection on wavelength and high contrast ratio.

Figure 6 presents a typical dependence of the twist angle of the LC layer on the luminous reflectance and the contrast ratio for the optimized cells.

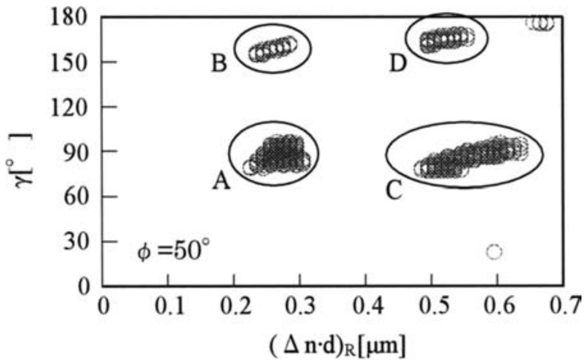

FIGURE 5 Relationships between γ and $(\Delta n{\cdot}d)_R$ required to obtain an achromatic image with a luminous reflectance of higher than 49% and a contrast ratio greater than 16:1.

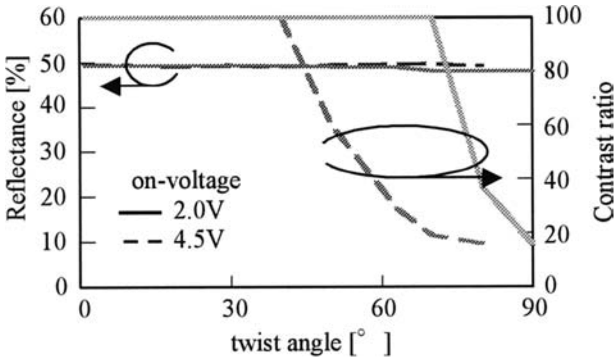

FIGURE 6 Typical dependence of the twist angle of the LC layer on the luminous reflectance and the contrast ratio for the optimized cells.

The results reveal that although the reflectance is about 50% for a twist angle of about 65° or less, it gradually decreases as the twist angle increases from 65°, and the reflectance becomes 47 to 48% at 90° independent of the on-voltage. However, though the contrast ratio exceeds 100:1 when the twist angle is small, it rapidly decreases when the twist angle increases from the threshold value. Therefore, a twist angle smaller than the threshold should be used. In addition, $(\Delta n{\cdot}d)_{LC}$ must exceed 0.2 μm to produce an LC panel. Figure 7 shows the twist angle dependence of $(\Delta n{\cdot}d)_{LC}$ for the optimum cells, taking the on-voltage as a parameter. The result demonstrates that $(\Delta n{\cdot}d)_{LC}$ increases when TFT-LCD on-voltage becomes low and that a practical twist angle is over 60° when the on-voltage is 4.5 V and that is 0° to 90° when the on-voltage is 2 V. There-

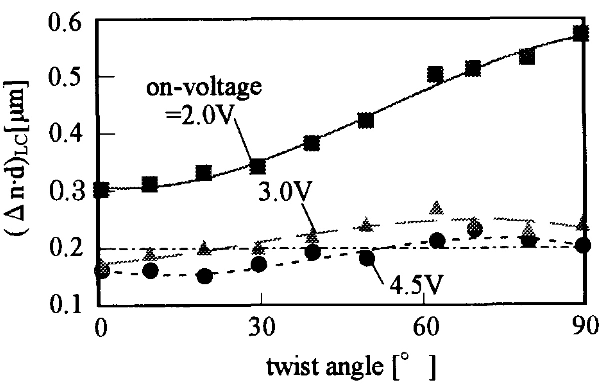

FIGURE 7 Twist angle dependence of $(\Delta n{\cdot}d)_{LC}$ for the optimized cells.

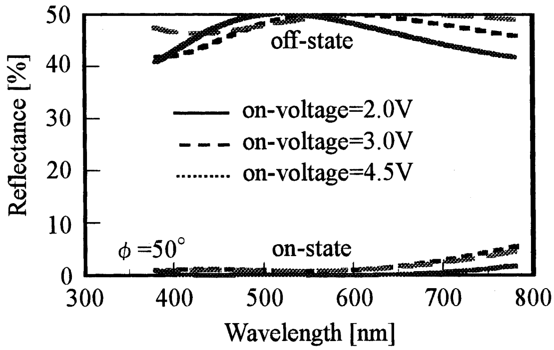

FIGURE 8 Reflection spectra for off-state and on-state for the optimized cells.

fore, Figure 7 indicates that the range of the cell that can be produced actually increases when the on-voltage is reduced.

Figures 8 and 9 depict the on-voltage dependence of the reflection spectra and locus of the color coordinate from the off-state for the optimized cell with a 50° twist as a typical example. Table III presents the values of $(\Delta n{\cdot}d)_{LC}$, β, $(\Delta n{\cdot}d)_R$ and γ in the optimized cell, and Table IV, the reflectance and contrast ratio obtained in the optimized cells. Figures 8 and 9 demonstrate than an achromatic image with a very small dependence of the reflection spectra on wavelength was obtained independent of TFT-LCD on-voltage. This is a very attractive property for a color display with conventional micro color filters. Figure 10 illustrates the applied voltage dependence of a luminous reflectance for the

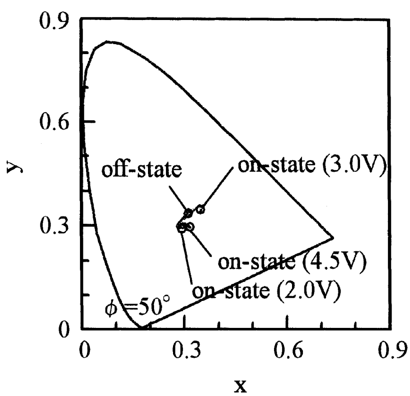

FIGURE 9 Locus of the color coordinate from off-state to on-state for the optimized cells.

TABLE III Typical Set of Optimized Parameters

on-voltage [V]	$(\Delta n \cdot d)_{LC}$ [μm]	β [°]	$(\Delta n \cdot d)_R$ [μm]	γ [°]
2.0	0.42	10	0.26	86
3.0	0.24	7	0.32	89
4.5	0.19	14	0.29	92

optimized cell presented in Table III. The bottom occurs in the characteristic curve at an on-voltage of 2 V. This bottom was confirmed to rapidly sharpen when the on-voltage was decreased further. In addition, the lower limit for the LCD using the material shown in Table 1 was about 2 V because $(\Delta n{\cdot}d)_{LC}$ rapidly increases when the on-voltage decreased from 2 V.

We examined why the superior picture quality was obtained in the reflective LCD shown in Figure 1 even when the on-voltage was reduced. The mechanism appears to essentially arise from the double-layered structure since $(\Delta n{\cdot}d)_{LC}$ increases with the decreasing of the on-voltage of the TFT-LCD. Residual birefringence in the driving cell increases when the on-voltage decreases. $(\Delta n{\cdot}d)_{LC}$ of the compensating cell is equivalently decreased by this residual birefringence because the twist directions of the driving cell and compensating cell are reversed. Therefore, only a quantity that equivalently decreases in the effect of the residual birefringence can be set as (($(\Delta n{\cdot}d)_{LC}$ of the compensating cell when the on-voltage is low in order to obtain a spectral reflectance equal to that when the on-voltage is low in order to obtain a spectral reflectance equal to that when the on-voltage is high. However, the optimum value must repeatedly be adjusted to $(\Delta n{\cdot}d)_{LC}$ to keep $(\Delta n{\cdot}d)_{LC}$ of the compensating cell and driving cell equal. However, the mechanism of this phenomenon is not as simple as that. Table III reveals that four parameters, $(\Delta n{\cdot}d)_{LC}$, β, $(\Delta n{\cdot}d)_R$ and γ, must also be adjusted simultaneously to obtain a spectral reflectance when the on-voltage is low equivalent to that when the on-voltage is high.

TABLE IV Typical Optical Properties in the Optimized Cells

On-voltage [V]	Luminous reflectance [%]	Contrast ratio
2.0	49.1	1023
3.0	49.0	54
4.5	49.4	60

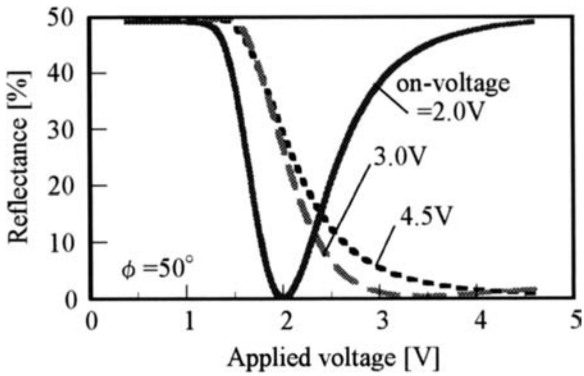

FIGURE 10 Applied voltage dependence of the reflectance for the optimized cells.

5. CONCLUSION

A reflective color LCD without backlighting is an important device for highly functional information terminals. We numerically analyzed the relationship between the electro-optical properties and the on-voltage of TFT-LCD in an achromatic reflective LCD that uses a single-polarizer double-layered TN-LCD with a retardation film, and found that the LCD exhibits an achromatic image with a superior luminous reflectance of about 50% and a very high contrast ratio, even if the on-voltage is reduced to 2 V. The power consumption can thus be decreased to about 1/6 that of a current reflective 5 V TFT-LCD in the on-state. In addition, we verified that this would be easy to produce, that there are multiple material alternatives, and that the range of the twist angle of the cell that can be produced actually increased, when the on-voltage decreases. However, it may be necessary to use materials with low viscosity and to minimize the cell gap when the on-voltage is decreased in order to avoid a coincidental reduction of response speed.

REFERENCES

[1] Ogawa, T., Fujita, S., Iwai, Y., & Koseki, H. (1998). SID 98 Digest., 217.
[2] Fukuda, I., Sakai, S., Kotani, K., & Uchida, T. (1994). *The Trans. of the IEICE*, *J77-C-II*, 355.
[3] Fukuda, I., Sakai, S., Kotani, K., & Uchida, T. (1995). *The Trans. of the IEICE*, *J78-C-II*, 86.
[4] Fukuda, I., Sakai, S., Kotani, K., & Kitamura, M. (1995). *Journal of the SID*, *3/2*, 83.
[5] Mukai, J., Kurita, T., Kaminada, T., Hara, H., Toyooka, T., & Itoh, H. (1994). SID 94 Digest, 241.
[6] Fukuda, I., Matui, N., Kotani, Y., & Uchida, T. (1998). *Proc. of SPID, Liquid Crystal II*, *3452*, 26.