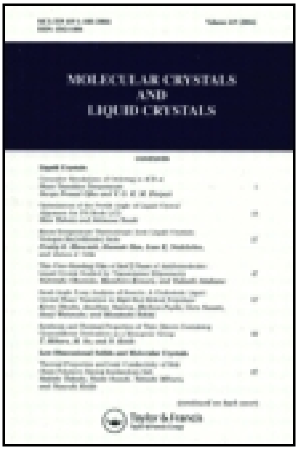

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Improvement of the Electro-Optical Properties of Film-Type Low Twisted Nematic Liquid Crystal Displays

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Improvement of the Electro-Optical Properties of Film-Type Low Twisted Nematic Liquid Crystal Displays

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We calculated the electro-optical characteristics of FLTN-LCDs using computer simulation of the dynamic behavior of liquid crystal molecules. Through the numerical calculation, it was clarified that the response time of the FLTN-LCDs is about 3 times faster than that of usual TN-LCDs when the identical cell gap is employed. To improve the other electro-optical characteristics, we determined a twisting angle to be about 60° from the view point of an inherent colorization and a gray scale capability and then optimized the material and design parameters of the FLTN-LCDs for the twisting angle of 60°. Under the optimized conditions, we were able to obtain FLTN-LCDs with a fast response time, a good gray-scale capability, a negligible inherent colorization, a high contrast ratio and a wide viewing angle.

Keywords: FLTN-LCDs; response time; gray-scale capability; contrast ratio

INTRODUCTION

According to broad applications of the liquid crystal displays (LCDs), a great effort has been made to improve electro-optical characteristics such as viewing angle, contrast ratio, gray-scale capability and so on. Especially, as the application fields of the LCDs have been expended to various multimedia displays as well as monitors, novel modes of LCDs with a full color capability and a high speed enough to represent moving pictures have been required. As a potentiality to the requirements, low twisted nematic liquid crystal displays (LTN-LCDs) having low twisting angle less than 90° were proposed [1,2]. In contrast to TN-LCDs, LTN-LCDs show a fast response time and a good gray-scale capability. However, some leakages at a black state of the LTN-LCDs lead to a low contrast ratio and an inherent background colorization. Recently, to suppress the leakage light, film-type low twisted nematic liquid crystal displays (FLTN-LCDs) using uniaxially stretched retardation films have been introduced [3-6].

To investigate the electro-optical properties of the FLTN-LCDs in detail, in this study, we obtained the dynamic molecular profiles from the Ericksen-Leslie equation [7-9] and then calculated optical transmittances from the 4×4 matrix given by Berreman [10,11]. Finally, we optimized the design and material parameters of the FLTN-LCDs to achieve a high contrast ratio, a wide viewing angle, and a negligible inherent colorization as well as a fast response time and a good gray-scale capability

CALCULATION PROCEDURE

To investigate the electro-optical characteristics of the FLTN-LCDs, we obtain the deformation profiles of the liquid crystals and then calculate optical transmittances by using the deformation profiles and the Berreman's 4×4 matrix. For analyzing the dynamic behaviors of the liquid crystals, we use the Ericksen-Leslie theory neglecting the inertial momentum of the molecules [7]. Applying a strain energy density f_s to the Ericksen-Leslie theory, we obtain

$$\gamma \frac{\partial n_i}{\partial t} = \frac{d}{dz}\left(\frac{\partial f_s}{\partial n_{i,z}}\right) - \frac{\partial f_s}{\partial n_i} + F_i + \lambda n_i \tag{1}$$

where γ is a rotational viscosity, $i = \{x, y, z\}$ is a cartesian component of x, y and z, and λ represents Lagrange multiplier introduced to maintain the molecular director $\vec{n} = (n_x, n_y, n_z)$ to be a unit vector $|\vec{n}| = 1$. Here, under an assumption of neglecting the surface term and the chirality the of liquid crystals, the strain energy density f_s is expressed as [8,9]

$$f_s = (-\frac{K_{11}}{12} + \frac{K_{22}}{4} + \frac{K_{33}}{12})G_1^{(2)} + (\frac{K_{11} - K_{22}}{2})G_2^{(2)} + (\frac{K_{33} - K_{11}}{4})G_6^{(3)} \qquad (2)$$

where K_{11}, K_{22} and K_{33} represent splay, twist and bend elastic constants of the liquid crystals, respectively. In equation (2), G 's are represented as

$$G_1^{(2)} = Q_{ij,k}Q_{ij,k}, \quad G_2^{(2)} = Q_{ij,j}Q_{ik,k}, \quad G_6^{(3)} = Q_{ij}Q_{kl,i}Q_{kl,j} \qquad (3)$$

where the convention of summing over repeated indices is used, and Q_{ij} 's are order tensors defined by de Gennes.

On the other hand, F_i in equation (1) represents a torque per unit volume induced by an external electric field. The torque components, F_x and F_y equal to zero, and

$$F_z = (\varepsilon_{\parallel} - \varepsilon_{\perp})n_z\left(\frac{\partial V}{\partial z}\right)^2 \qquad (4)$$

where $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are parallel and perpendicular components of the dielectric constants of liquid crystals, respectively, and V stands for a potential distribution function inside the liquid crystal cell. The potential distribution can be calculated by the following equation :

$$\frac{\partial}{\partial z}\left((\varepsilon_{\parallel} - \varepsilon_{\perp})n_z\frac{\partial V}{\partial z}\right) = 0 \qquad (5)$$

Boundary conditions of the differential equations (1) and (5) are given by the rubbing directions of the upper and lower plates, and by the voltages applied to the pixel and common electrodes, respectively. From the differential equations and the boundary conditions, we can obtain the dynamic director profiles of the liquid crystals using a numerical calculation such as a finite difference method. Finally, with the calculated deformation profiles, the optical transmittances of the liquid crystals are calculated from the Berreman's 4×4 matrix method by considering the liquid crystals as broken up into many thin layers and treating each as if it had homogeneous anisotropic optical parameters [10,11]. The design and material parameters used in the calculation are listed in Table 1.

TABLE 1. List of parameters used in the simulation

Input parameter	Value
Cell thickness d	4.5[μm]
Ordinary refractive index n_o	1.4745
Perpendicular dielectric constant $\varepsilon_\perp$	3.1
Parallel dielectric constant $\varepsilon_\parallel$	8.4
Splay elastic constant K_{11}	13.9×10^{-12} [N/m]
Twist elastic constant K_{22}	6.5×10^{-12} [N/m]
Bend elastic constant K_{33}	18.2×10^{-12} [N/m]
Input wavelength λ	550[nm]

RESULTS AND DISCUSSION

We investigated the electro-optical properties of the LTNs and the FLTN-LCDs for the symmetric A structures suggested by Palmer [5,6], which operates efficiently at a normally white mode by optimizing the directions of crossed polarizers and the fast axis of a retardation film with respect to the rubbing directions of the upper and lower plates. The optimum arrangement is depicted in Figure 1.

For several twisting angles of 0°, 30°, 60°, and 90°, which corresponds to the conventional TN-LCDs, we calculated the value of Δnd of the liquid crystals which satisfies the first maximum conditions at a non-selected voltage and represented the results in Table 2. The values of Δnd of the retardation films are extracted to minimize the leakages of the transmission at a selected voltage. As shown in Table 2, for the twisting angles above 60°, the gray scale capability is improved as the twisting angle decreases. In case of the twisting angle under 60°, there are not much differences in gray scale capability.

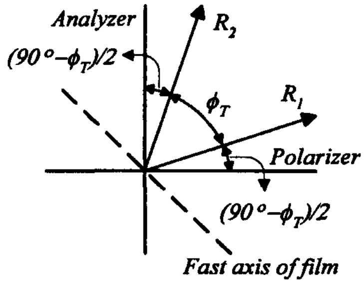

FIGURE 1. Symmetric A structure of the FLTN-LCDs; R_1 and R_2 stand for the rubbing directions of the lower and upper plates, respectively, and ϕ_T for the total twisting angle.

TABLE 2. Optimized retardation values Δnd of the LTN-LCDs and the retardation films, and the steepness of 0°, 30°, 60° FLTN-LCDs and 90° TN-LCD with 2° pretilt angles.

Twist angle ϕ_T	0°	30°	60°	90°
Δnd_{cell} [μm]	0.275	0.295	0.35	0.48
Δnd_{film} [μm]	0.044	0.041	0.027	-
$p_o = V_{50}/V_{90} - 1$	0.37	0.36	0.30	0.14

Under the conditions given by Table 2, we calculated the electro-optical characteristics of the LTN and FLTN-LCDs, and showed the results in Figure 2. Figure 2 shows that the leakages of the LTN-LCDs at a black state are markedly suppressed by compensating retardations of the liquid crystals with retardation films. Figure 3 describes the dynamic molecular profiles of a LTN-LCD with 60° twisting angle. Compared to the TN-LCD, the distribution of the liquid crystal molecules is deformed more rapidly after an electric field is applied. Thus, the response time is expected to become considerably faster.

On the other hand, as already shown in Table 2, the optimized value of Δnd of the LTN-LCDs decreases as the twisting angle decreases, and thus the cell gap can be reduced for low twisting angles. This leads to a fast response time.

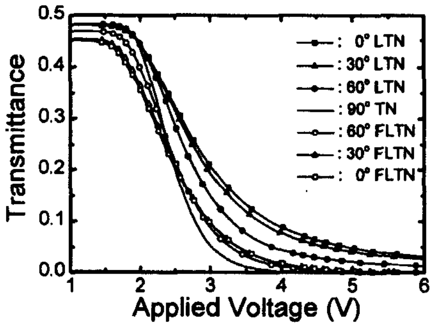

FIGURE 2. Transmittance-voltage curves for LTN, FLTN and TN-LCDs.

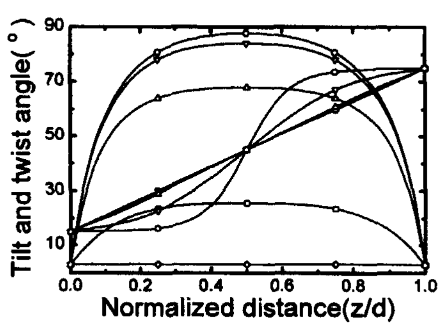

FIGURE 3. Dynamic molecular deformation profiles of LTN-LCDs. Diamonds, squares, triangles, inverted triangles and circles represent 0, 4, 8, 12 and 16 *msecs* after an electric field is applied.

Therefore, to investigate the effect of the twisting angle on the response time, we fixed the cell gaps at 4.5 μm, which is used usually in the TN-LCDs, and then varied the values of Δn according to optimized retardations of the liquid crystals for several twisting angles. As shown in Figure 4, the response time, especially a decay time, of the FLTN-LCDs becomes faster as the twisting angle decreases. This can be interpreted by the tendency for the liquid crystals to recover more rapidly from the elastic deformation as the twisting angle becomes smaller. However, remarkable variations can be hardly seen for the

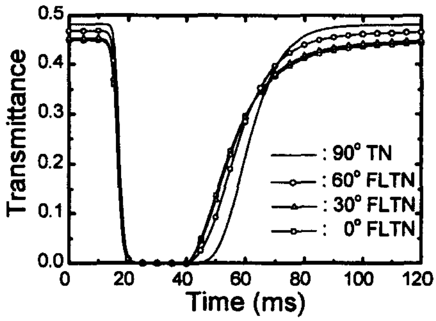

FIGURE 4. Transmittance-response curves of FLTN and TN-LCDs. The pulse is applied at 10ms and removed at 40ms.

twisting angles below 60°.

Figure 5 represents the color coordinates for the variation of Δnd of the liquid crystals. It can be seen from Figure 5 that the inherent colorization due to the variation of Δnd increases gradually with decreasing the twisting angle, but it may be negligible for the twisting angles of more than 60°.

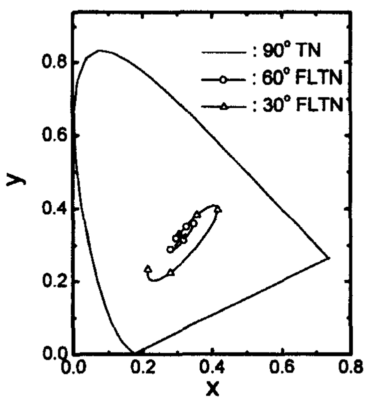

FIGURE 5. CIE chromaticity diagram of FLTN and TN-LCDs.

From Figures 2, 4 and 5, considering a gray-scale capability, a response time and an inherent colorization simultaneously, we determined the twisting angle

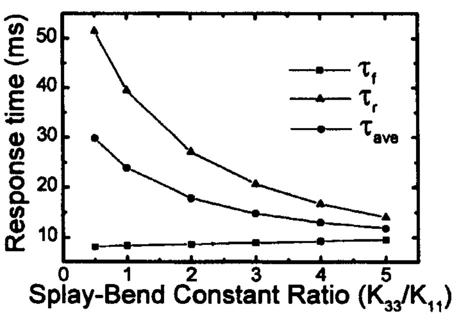

FIGURE 6. Splay-Bend constant ratio dependence of the response time. τ_f, τ_r and τ_{ave} represent falling, rising and average response times.

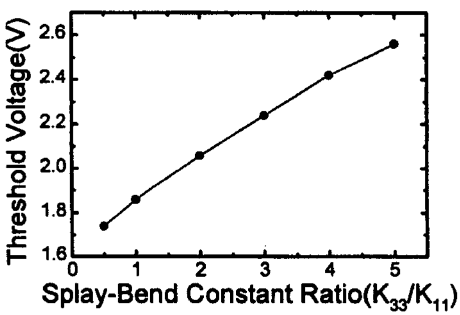

FIGURE 7. Splay-Bend constant ratio dependence of a threshold voltage.

to be about 60°. The response time of the 60° FLTN-LCDs is calculated to be about 3 times faster than that of the usual TN-LCDs when the same cell gap as used in the TN-LCDs is employed. For the same liquid crystals as used in the TN-LCDs, the cell gap can be reduced to 3 μm or so by considering the optimal value of Δnd. In this case, the response time can be reduced to about one fifth of that of the TN-LCDs.

Moreover, we investigated elastic effects on a response time and a threshold voltage. Figure 6 depicts that a response time, especially a rising time, becomes faster significantly with the ratio of K_{33} to K_{11}. Figure 7 reveals that a threshold voltage increases monotonously with the parameter of K_{33}/K_{11}. Therefore, to achieve the FLTN-LCDs with a low threshold voltage and a fast response time at the same time, an optimum design considering the results shown in Figures 6 and 7 is required.

Relating to a viewing angle, since the minimum transmittances of the FLTN-LCDs at a black state are suppressed to very low levels over quite wide ranges as shown in Figure 8, it is considerably improved when compared with the usual TN-LCDs.

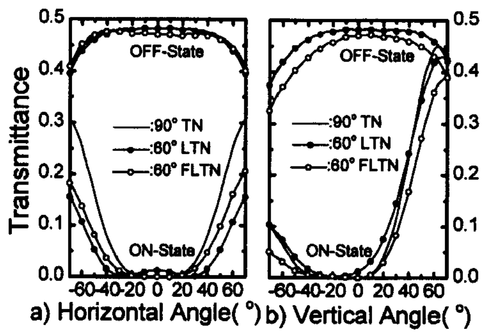

FIGURE 8. a) Horizontal and b) vertical viewing angle dependencies of LTN, FLTN and TN-LCDs.

CONCLUSIONS

To investigate the electro-optical properties of FLTN-LCDs in detail, in this study, we calculated dynamic molecular profiles from the Ericksen-Leslie equation and then obtained optical transmittances from the 4×4 matrix given by Berreman. Through the numerical calculations, it was clarified that the response time of the FLTN-LCDs is about 3 times faster than that of the usual TN-LCDs when an identical cell gap is employed. For the same liquid crystals as used in the TN-LCDs, the cell gap can be reduced to 3 μm or so by considering the optimal value of Δnd. Thus, the response time can be reduced to about one fifth of that of the TN-LCDs. To improve the other electro-optical characteristics, we determined the twisting angle to be about 60° from the view point of an inherent colorization and a gray scale capability. The other material and design parameters of the FLTN-LCDs were optimized for the twisting angle of 60°. Under the optimized conditions, we were able to obtain FLTN-LCDs with a fast response time, a negligible inherent colorization, a good gray-scale capability, a high contrast ratio and a wide viewing angle.

Acknowledgements

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