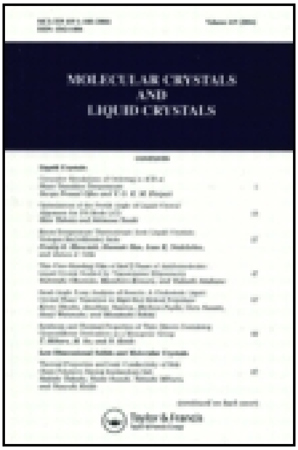


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# Optical Designing for a Bright Reflective Direct-Matrix-LCD using Homeotropically Aligned Liquid Crystal

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# Optical Designing for a Bright Reflective Direct-Matrix-LCD using Homeotropically Aligned Liquid Crystal

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We have analyzed and designed a reflective direct-matrix-LCD with homeotropic alignment. We have optimized parameters of the compensation films, cell thickness and pretilt angle, and have obtained sufficiently high reflectance, high contrast, large gray scale and good legibility.

*Keywords:* reflective LCDs; direct-matrix-LCDs; homeotropic alignment

## INTRODUCTION

A reflective matrix LCD is promising as a display with a large information content for a portable equipment. Seki et al. has proposed a basic idea for a reflective direct-matrix-LCD composed of a front scattering film, single pollazer, a quater-wave plate, a retardation film, a homeotropic liquid crystal layer and a reflector[1]. This method is expected to get high reflectance, high contrast, wide gray scale and good legibility using a design rule of Ishinabe et al. for a quater-wave plate [2] and that of Miyashita et al. for a optical compensate film[3].

However, it has not yet been attained to compensate both select and non-select states by the retardation film in a wide viewing angle range. To solve this problem we have investigated the optimum design condition of the reflective direct-matrix-LCD with homeotropic alignment by computer simulation.

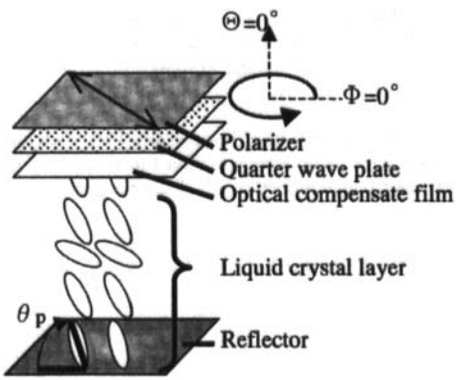



FIGURE 1 Structure of the reflective LCD with homeotropic alignment.

## DESIGNING AND RESULT

In order to get the maximum contrast for the LCD with configuration as shown in Fig. 1, the following equation must be satisfied:

$$d\Delta n(v_s) - d\Delta n(v_{ns}) = \frac{\lambda}{4} \quad (1)$$

or

$$\Delta n(v_s) - \Delta n(v_{ns}) = \frac{\lambda}{4d}, \quad (2)$$

where $\Delta n_{(Vs)}$ and $\Delta n_{(Vns)}$ are respectively birefringence of the liquid crystal layer at applied voltages of select and non-select states, Vs and Vns, and d is cell thickness. We have examined the effective condition to get retardation change of $\lambda/4$ by choosing material and device parameters suitably. Table I shows material constants of the liquid crystal used in this examination as a standard if it is not specially mentioned.

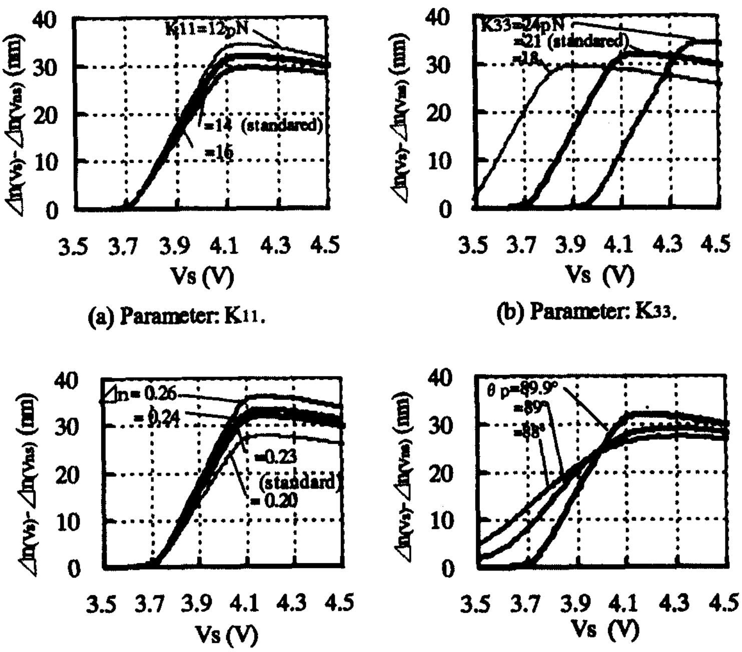
TABLE I. Material parameters of the standard liquid crystal

| Elastic constants | | Refractive index at $\lambda$ =550nm | | Dielectric constant | |
|---|---|---|---|---|---|
| $K_{11}$, pN | $K_{33}$, pN | $n_{\perp}$ | $\Delta n$ | $\varepsilon_p$ | $\Delta\varepsilon$ |
| 14 | 21 | 1.51 | 0.23 | 4.85 | -1.66 |

Fig. 2 shows $[\Delta n_{(Vs)} - \Delta n_{(Vns)}]$ as a function of Vs when Vs/Vns is fixed to 1.0958 considering the optimum bias driving method for 1/120 duty, pretilt angle $\theta_p$ is 89.9° except for Fig. 2(d) and the wavelength $\lambda$ of incident light is 550nm. If the maximum value of $[\Delta n_{(Vs)} - \Delta n_{(Vns)}]$ in each figure of Fig. 2(a)~(d) is denoted by $[\Delta n_{(Vs)} - \Delta n_{(Vns)}]_{max}$, it increases with increase of $K_{33}$, $\Delta n$ and $\theta_p$, and with decrease of $K_{11}$. Considering Eq.(2), the minimum cell thickness is expressed as follows:

$$d_{min} = \frac{\lambda/4}{[\Delta n(Vs) - \Delta n(Vns)]_{max}} \quad . \tag{3}$$

As mentioned above, the cell thickness d must be thicker than $d_{min}$ to get maximum contrast, while d should be as thin as possible in the view point of response time. In the case of the standard liquid crystal mentioned in Table I, $d_{min}$ is 4.3 $\mu$m.




(a) Parameter: K11.

(b) Parameter: K33.

(c) Parameter: ⊿n.

(d) Parameter: θ p

FIGURE 2 $[\Delta n_{(Vs)} - \Delta n_{(Vns)}]$ vs. Vs when Vs/Vns is fixed to the optimum bias condition of the 1/120duty.

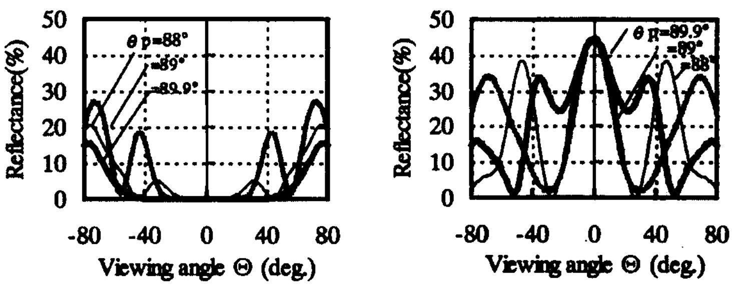
For the next step, we have examined the viewing angle property of the LCD in the term of the cell thickness d and pretilt angle $\theta_p$, we have focused on the polar angle $\Theta$ of the direction of $\Phi$=90° / 270°, which are the worst azimuth.

<u>Normally black type (NB-type)</u>

Fig. 3 shows the viewing angle dependence on the reflectance at the cell thickness d=5.0 $\mu$m as parameter of the pretilt angle $\theta_p$, where the direction of the observation is right angle to that of the incidence. When the pretilt angle $\theta_p$ of liquid crystal molecules is close to 90°, a low reflectance region widens but a sinking area of reflection in white state (Θ=15~40° ) reduces.

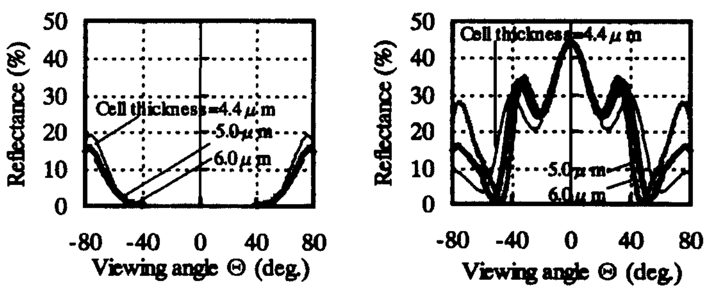
Fig. 4 shows the same properties except that the cell thickness d is parameter. It is seen from this figure that the sinking area of reflection in white state reduces when d is increased.

Here, if we suppose a typical condition required for the practical application to be the reflectance of the white state higher than 25% and that of the black state lower than 2.5% in the viewing angle range of $-40° \leqq \Theta \leqq 40°$, it is necessary that $\theta_p \geqq 89.9°$ and $d \geqq 5\,\mu m$.




(a) Black state (b) White state

FIGURE 3 The viewing angle characteristics of the NB-type for various pretilt angle $\theta_p$ at the cell thickness d=5 μm.




(a) Black state (b) White state

FIGURE 4 The viewing angle characteristics of the NB-type for the various cell thickness at the pretilt angle $\theta_p$=89.9° .

For the normally black type (NB-type) the compensation is made at the black state or non-select state which correspond to a low voltage such as 3.7V.

Fig. 5 shows the Nz value of the retardation film to compensate the liquid crystal with various pretilt angle $\theta_p$ and applied voltage from 3.7V to 4.5V. Here, Nz denotes birefringent parameter for the normal of the retardation film and is defined as

$$Nz = \frac{n_y - n_z}{n_x - n_z} , \tag{4}$$

where $n_x$, is refractive index parallel to the stretched direction (x) of the retardation film, $n_y$ is that perpendicular to x but parallel to the film plane and $n_z$ is that for normal of the film. On the condition that the pretilt angle $\theta_p$ of liquid crystal molecules is close to 90°, the Nz parameter to compensate the LC-cell becomes large at low voltage as shown in Fig. 5. In this case the retardation film becomes very close to the negative optical compensate film, namely $n_y$-$n_z \gg n_x$-$n_y$. Therefore, we have used a negative optical compensate film instead of a biaxial retardation film and have realized wide viewing angle characteristics as shown in Fig. 6.

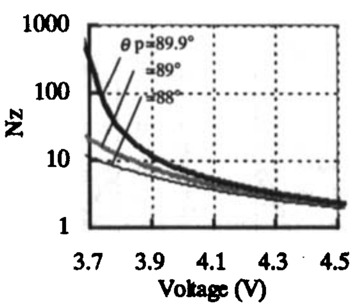



FIGURE 5 The Nz value of the retardation film to compensate the reflective LCD with homeotropic alignment as a function of voltage.

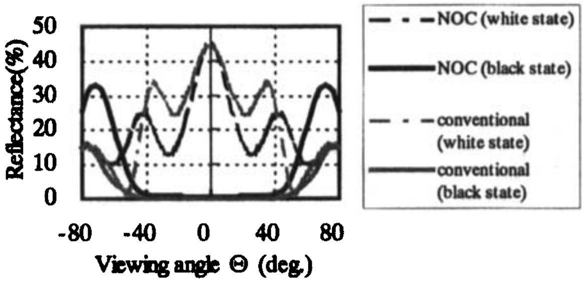


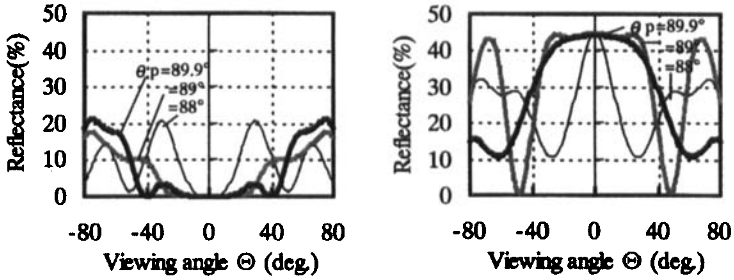

FIGURE 6 The comparison of viewing angle characteristics between the conventional biaxial retardation film and the negative optical compensate film (NOC film). The pretilt angle and the cell thickness are $\theta_p$=89.9 and d= 5 $\mu$ m, respectively.

**Normally white type (NW-type)**

The effect of pretilt angle $\theta_p$ and cell thickness on the normally white type display (NW-type display) is described as follows:

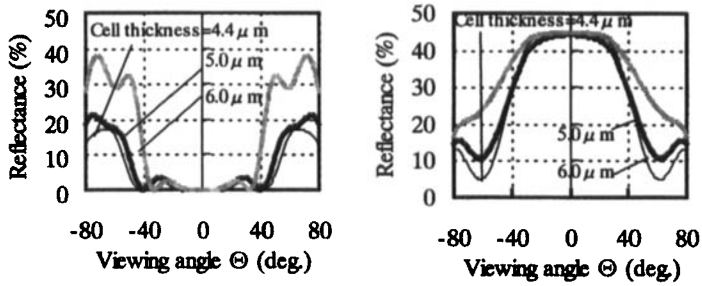
- When the pretilt angle $\theta_p$ is closed to 90° at an even cell thickness, the viewing angle of the low reflection area in black state and of the high reflection area in white state increases as shown in Fig. 7.
- When the cell thickness increases, the high reflectance area in white state increases as shown in Fig. 8.
- According to decrease of the cell thickness, the light leakage at the viewing angle Θ=30° in the black state increases as shown in Fig. 8(b). While, with the increase of cell thickness this phenomena is restrained, with sacrifice of reduction in viewing angle range of the white state in Fig. 8(a).

Here, considering a typical requirement as the reflectance of the white state higher than 25% and that of the black state lower than 2.5% in the viewing angle range of $-40° \leqq \Theta \leqq 40°$ , it is necessary from Fig. 7 that $\theta_p \geqq 89.9°$ and d$\geqq$5 $\mu$ m just the same as the NB-type.




(a) Black state (b) White state

FIGURE 7 The viewing angle characteristics of the NW-type for various pretilt angle $\theta_p$ at the cell thickness d=5 μm.




(a) Black state (b) White state

FIGURE 8 The viewing angle characteristics of the NW-type for various cell thickness at the pretilt angle $\theta_p$=89.9° .

## CONCLUSION

We have investigated the characteristics of the reflective LCD with homeotropic alignment. Its contrast is determined by the maximum variation of the retardation, $[d\Delta n_{(Vs)} - d\Delta n_{(V\infty)}]_{max}$, because this value is rather smaller than $\lambda/4$ . This value increases with increase of the elastic constant $K_{33}$, $\Delta n$ of the liquid crystal, cell thickness d and pretilt angle $\theta_p$, and with decrease of the elastic constant $K_{11}$. On the other hand, it is desirable to decrease the thickness d as small as possible to get fast response.

As for the viewing angle, the optical compensate film with large Nz value is preferable to obtain wide viewing angle range in the plane parallel to the inclination plane of the liquid crystal molecules.

Based on these design concept, the reflective LCD with homeotropic alignment has been optimized and high reflectance at the white state (≧25%) and low reflectance in the dark state (≦2.5%) in the range of polar angle ±40°, have been obtained.



## *References*

[1] H. Seki, M. Itoh and T. Uchida : Euro Display '96, p.464(1996).
[2] T. Ishinabe, T. Uchida, T. Miyashita and M. Suzuki : Digest of AM-LCD'97, p.135(1997).
[3] T. Miyashita, P. J. Vetter, Y. Yamaguchi and T. Uchida : J. of SID, 3/1, p.29(1995).