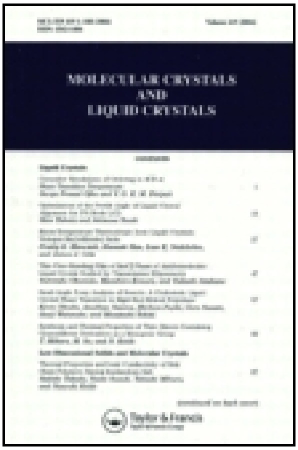

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Highly-multiplexed Large-area Achromatic Liquid Crystal Display

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Highly-multiplexed Large-area Achromatic Liquid Crystal Display

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Influences of retardation and polarizer configuration on background color, background brightness and contrast ratio have been studied for a ST LCD with a twist angle of 240 degrees. There exists an optimum polarizer configuration which gives an achromatic background color and the highest contrast ratio for each retardation. When the optimum polarizer configuration is used for each retardation, a bright background and a high contrast ratio are obtained as the retardation is larger. On the other hand, the background color becomes more achromatic as the retardation is smaller. Therefore, it is necessary to optimize cell conditions taking account of a balance of the background brightness, contrast ratio and background color. It is concluded that the optimum retardation ranges from 0.59 to 0.60 μm.

On the basis of the optimization of a LC material as well as the retardation and polarizer configuration, an achromatic ST LCD with 640 × 400 pixels in an A4 page size and a twist angle of 240 degrees which operates under a 1/200 duty multiplexing drive has been successfully developed. The achromatic ST LCD has an excellent display performances such as not only almost the same achromatic background color as that of a conventional TN LCD but also a high contrast ratio and a wide viewing angle.

1. INTRODUCTION

Recent rapid progress of information technology increases demands of a realization of a display device with a high information content and high display performance. A liquid crystal display (LCD) occupies the attention as such a display device thanks to their excellent features such as thin design, light weight, large area, low power consumption and low operation voltage. Twisted nematic (TN) LCD has been used for a dot matrix LCD and a TN LCD with 640 × 200 pixels multiplexed at a 1/100 duty cycle has been available in market. It has, however, some problems such as a low contrast ratio and narrow viewing angle under a higher multiplexing drive than 1/100 duty cycle. This poor display performance has limited the capacity of information content of TN LCD.

On the other hand, supertwisted birefringence effect (SBE or ST) LCDs[1-4] whose twist angle is larger than 180 degrees have been developed and drawn attention as a new LCD with a high contrast ratio and wide viewing angle. Nevertheless, their display color is not achromatic and is black on yellow (yellow mode), white on blue (blue mode) or another color compensated using a color polarizer because they operate by a birefringence effect. These display colors are not suitable for not only human eye's taste but also an application for a multicolor display combining a color filter. Recently, attempts to realize an achromatic background color in ST LCD using a small retardation around 0.5 μm have been investigated.[5-7]

In this paper, influences of retardation and polarizer configuration on background color, background brightness and contrast ratio have been studied for a ST LCD. On the basis of the study, cell condition and liquid crystal material have been optimized. Display performances of a developed achromatic ST LCD with 640 × 400 pixels in an A4 page size and a twist angle of 240 degrees which operates under a 1/200 duty multiplexing drive are described.

2. OPTIMIZATION OF RETARDATION AND POLARIZER CONFIGURATION

2.1 Experimental

An alignment layer of a cell used in experiments was a rubbed polyimide layer. The angle between rubbing direction of front and rear substrates was 240 degrees counterclockwise from front to rear substrate. The pretilt angle was so small that its effect on retardation was negligible. Cell thickness was controlled to be about 6.5 μm and the cell thickness d of each cell was measured with Canon's interference thickness meter TN-230N.

Four kinds of liquid crystal materials LC-1,2,3 and 4 which consist of mainly PCH substants were used. They had a different birefringence Δn value from each other. Birefringence Δn of the LC materials LC-1,2,3 and 4 was 0.100, 0.090, 0.087 and 0.810, respectively and so the retardation R $(= \Delta nd)$ becomes about 0.65, 0.59, 0.57 and 0.53 μm, respectively. A chiral dopant S-811 (E. Merck) was mixed

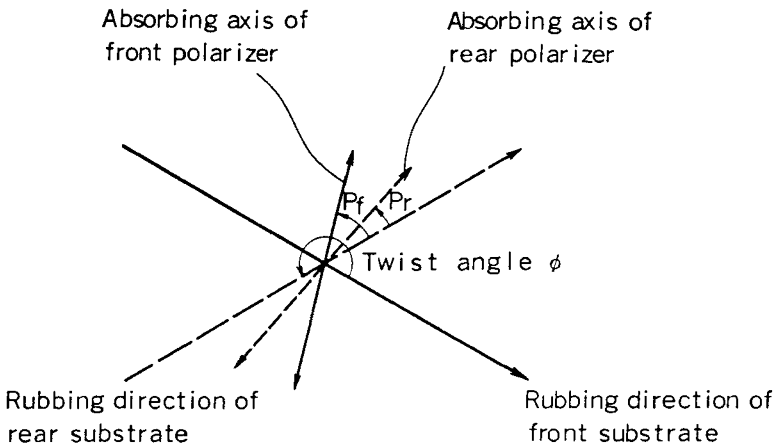

FIGURE 1 Definition of rubbing direction and polarizer axis.

in the LC materials. The LC cells were set between polarizers LLC2-82-18 (Sanritsudenki Corp.) In this paper, an arrangement of polarizer axis is defined as shown in Figure 1. Rear polarizer angle Pr is an angle between the rubbing direction of the rear substrate and the absorbing axis of the rear polarizer. Front polarizer angle Pf is an angle between the rubbing direction of the rear substrate and the absorbing axis of the front polarizer. Angles Pr and Pf are measured counterclockwise.

Intensity and chromaticity of transmitted light through the four kinds of the cells were measured by Topcon's luminance meter (BM-5) in an off and on state. A luminous compensation filter was used in the transmittance measurement. No voltage was applied to the cell in the off state and a voltage larger than a threshold voltage of each cell by 0.20 volts was applied in the on state. Since a threshold voltage of each cell was about 2 volts, the applied voltage for the on state is considerably larger than a RMS voltage for a selected pixel under a 1/200 duty multiplexing drive. Sharpness of electro-optical characteristics of the LC materials used in this experiments was so small that the light transmission can be changed almost perfectly by the voltage in the on state. So a difference of display characteristics caused by a difference of the sharpness is thought to be negligible. A ratio of the transmissions in the on and off state is defined as contrast ratio CR. Chromaticity in the off state corresponds to a background color and that in on state does to a displayed image color.

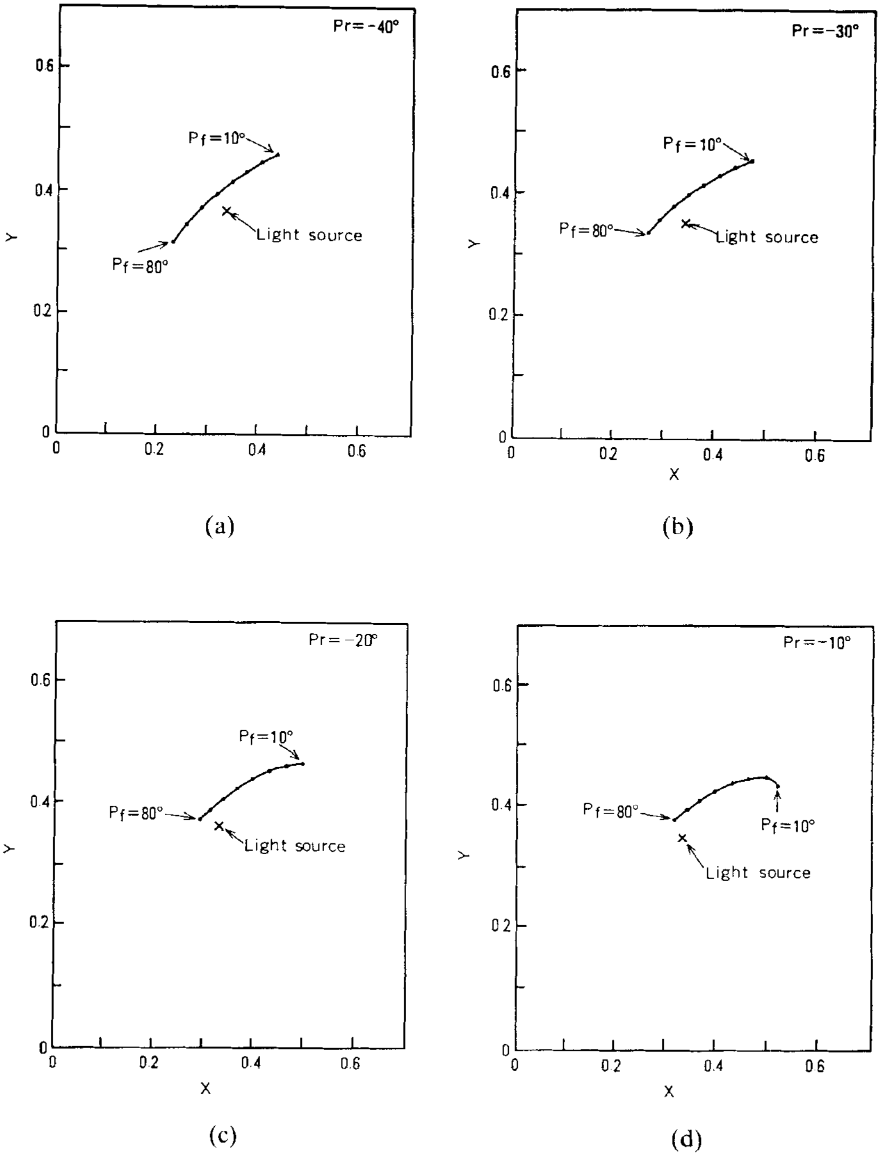

FIGURE 2 Background color vs. polarizer configuration for the retardation of 0.594 μm.

2.2 Results and Discussion

2.2.1 Dependence of polarizer configuration on background color Figure 2(a), (b), (c) and (d) show a change of chromaticity of background color in the case of retardation R of 0.594 μm with LC material LC-2 and cell thickness of 6.6 μm. The background color changes from yellow, pale green to pale blue as shown in Figure 2(a), when the front polarizer angle Pf is changed from 10 to 80 degrees for the rear polarizer angle Pr of −40 degrees. By comparing Figure 2(a), (b), (c) and (d), it is recognized that loci of the background color are almost the same even when the polarizer configuration is changed. It means that almost the same background color can be obtained by changing the polarizer configuration.

On the other hand, the transmission through a cell with twist angle ϕ in the off state is given by[8]:

$$\begin{aligned} T = \{&\cos\beta \cos(\phi - Pf + Pr) \\ &+ \sin\beta \cdot (1 + \alpha^2)^{-1/2} \sin(\phi - Pf + Pr)\}^2 \\ &+ \alpha^2/(1 + \alpha^2) \times \sin^2\beta \times \cos^2(\phi - Pf - Pr) \end{aligned} \tag{1}$$

$$\alpha = \pi \cdot \Delta nd/\phi\lambda \tag{2}$$

$$\beta = \phi \cdot (1 + \alpha^2)^{-1/2}. \tag{3}$$

Figure 3 shows calculated curves of the background color of a cell with 0.594 μm retardation by these equations changing the polarizer configuration Pr and Pf. In the region near to achromatic color, the background color doesn't change regardless of the polarizer configuration in the same way as the experimental results.

According to an actual observation of the background color by human eyes, such a pale green color as the background color, for instance, with Pr of −40 degrees and Pf of 40 degrees was felt achromatic for human eyes. In the case of retardation of 0.594 μm, such polarizer configurations as (Pr, Pf) = (−40°, 40°), (−30°, 49°), (−20°, 56°) and (−10°, 68°) bring achromatic background color as shown in Figure 2.

Figure 4 shows the polarizer configurations which gives the achromatic background color for each retardation. The larger the retardation R is, the larger the absolute values of polarizer angles Pr and Pf become.

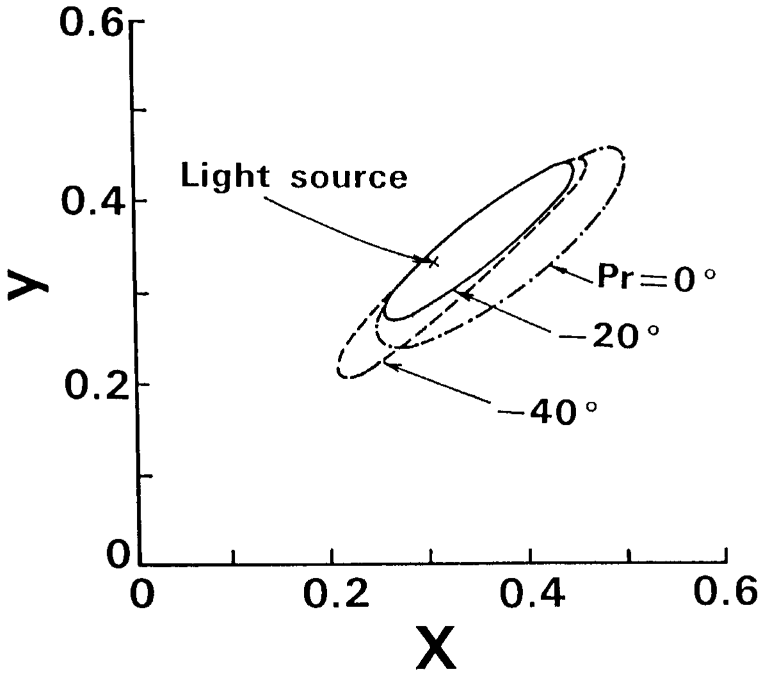

FIGURE 3 Calculated curves of the background color of a cell with 0.594 μm retardation (twist angle = 240°).

2.2.2 Dependence of polarizer configuration on contrast ratio CR Figure 5 shows a change of contrast ratio CR when the polarizer configuration is changed for a cell with the 0.594 μm retardation. In the same figure, the polarizer configurations which give an achromatic background color are indicated with arrows. A maximum value of contrast ratio CR increases with an increase of absolute value of Pr. But the polarizer configuration which gives the maximum contrast ratio does not correspond to the polarizer configuration which gives an achromatic background color. According to Figure 5, it is concluded that the optimum polarizer configuration which gives both an achromatic background color and the largest contrast ratio is Pr of −25 degrees and Pf of 52 degrees in the case of retardation R of 0.594 μm.

2.2.3 Optimum polarizer configuration for each retardation There are also the optimum polarizer configuration which gives both an achromatic background color and the largest contrast ratio, when the retardation is changed by using other LC materials. Figure 6(a),

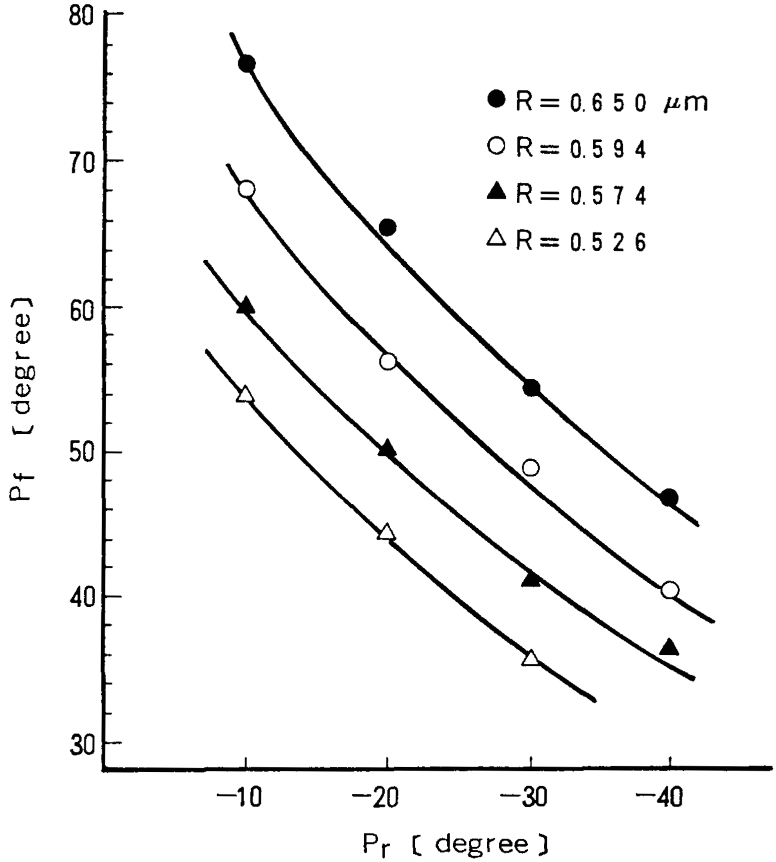

FIGURE 4 A polarizer configuration which gives an achromatic background color for each retardation.

(b) and (c) show a retardation dependence of the optimum polarizer angle Pr0, Pf0 and an angle between the front and rear polarizers Pf0−Pr0. Absolute values of Pr0 and Pf0 increase with an increase of retardation. And Pf0−Pr0 also increases with an increase of the retardation.

2.2.4 Optimum value of retardation R Retardation dependences of background transmission Toff and contrast ratio CR are shown in Figures 7 and 8, respectively, when the optimum polarizer configuration Pr0, Pf0 is used for each retardation. The larger the retardation R is, the larger both the Toff and CR become. A large retardation brings the bright background and the high display contrast ratio.

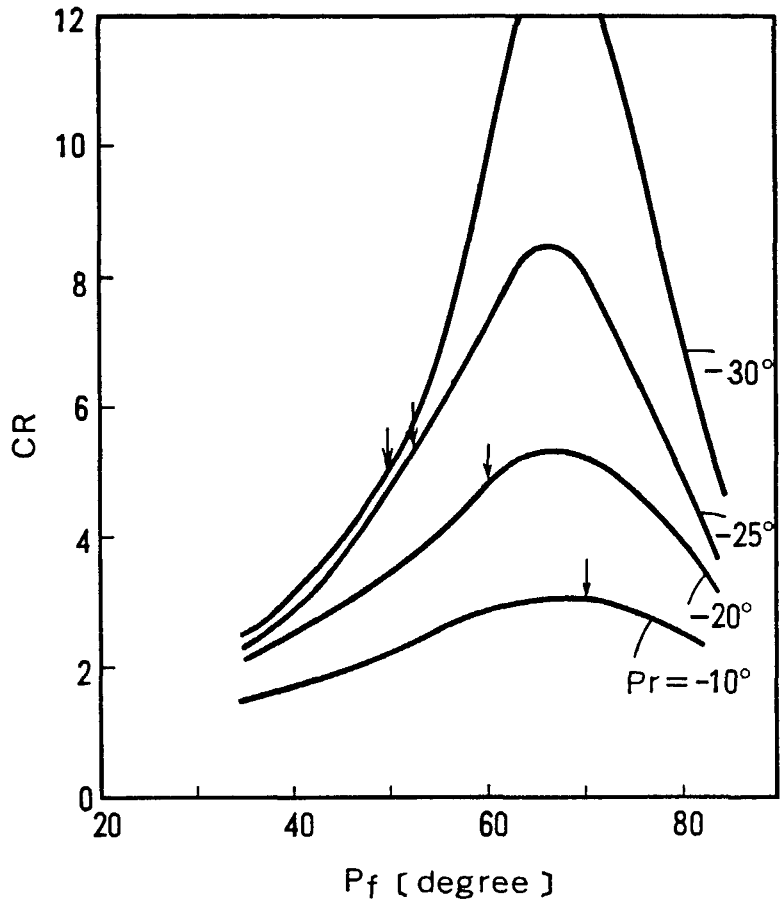

FIGURE 5 Contrast ratio CR vs. polarizer configuration for the retardation of 0.594 μm.

A background color slightly changes with a change of retardation R even when the polarizer configuration Pr0, Pf0 is optimized so that the background color becomes achromatic for each retardation as already shown in Figure 6. Figure 9 shows loci of the background color of the cell with each retardation, when the front polarizer angle Pf is changed using the optimum rear polarizer angle Pr0 for each retardation. Chromaticities of background colors with the optimum polarizer configuration Pr0, Pf0, which were already shown in Figure 6(a) and (b), are shown with circles. The background color becomes more achromatic as the retardation is smaller. According to an ob-

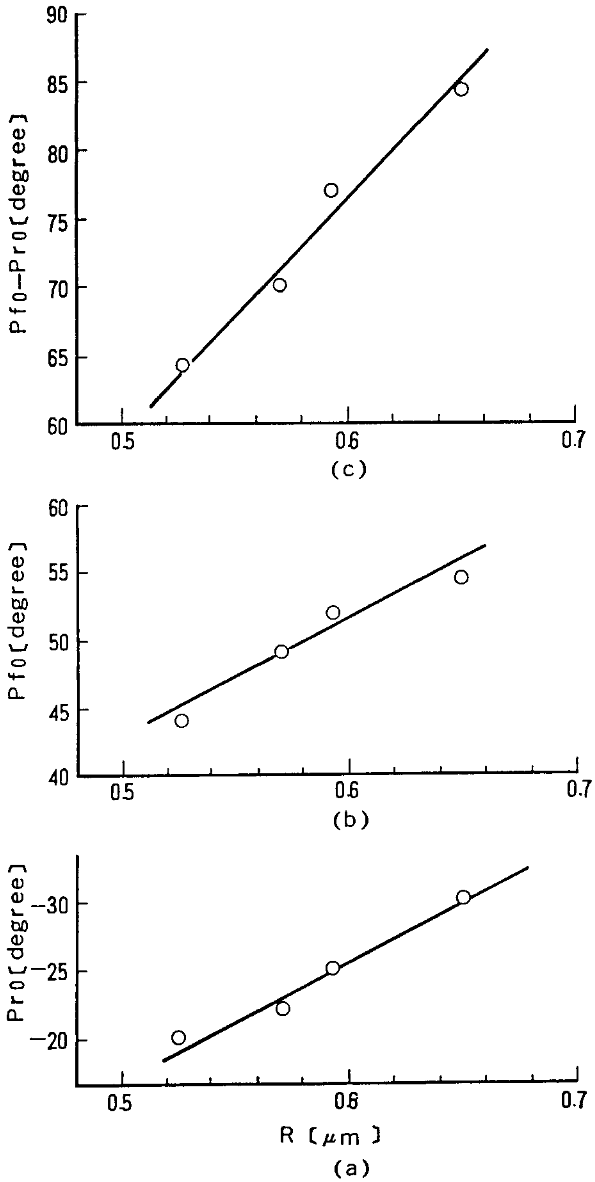

FIGURE 6 The optimum polarizer configuration vs. retardation.

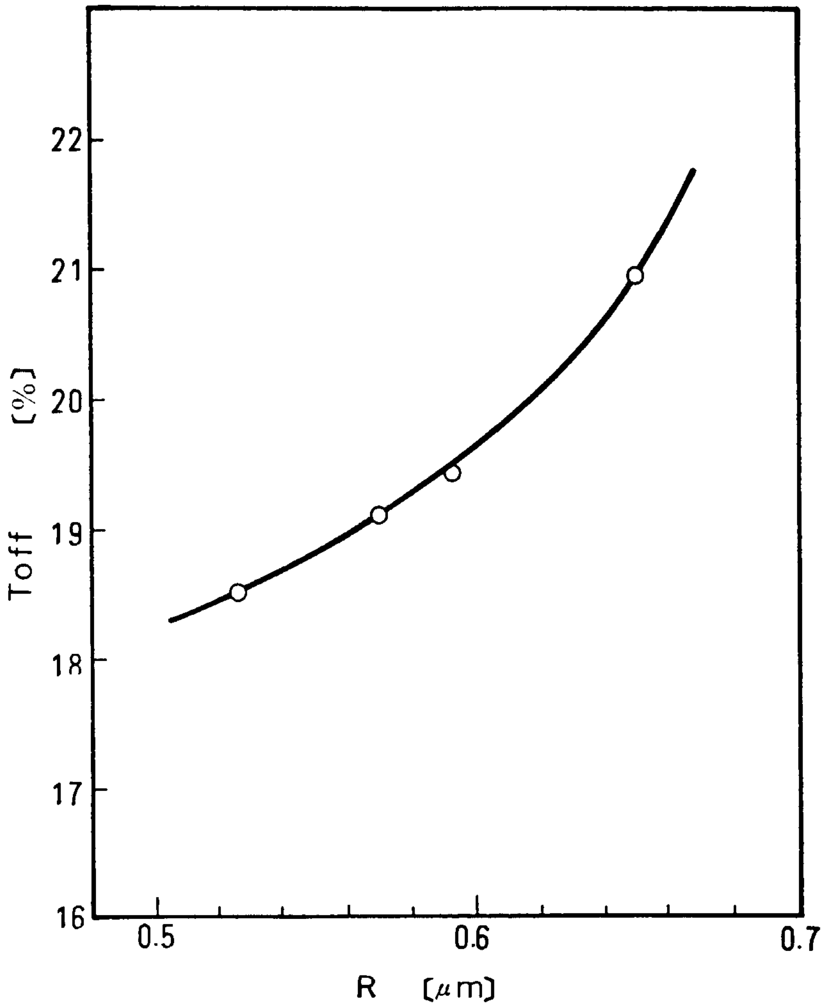

FIGURE 7 A retardation dependence of the background transmission Toff when the optimum polarizer configuration is used for each retardation.

servation by human eyes, background color with a smaller retardation than 0.6 μm as shown with a shaded area in Figure 9 was felt acceptably achromatic.

There is an inverse relation between a retardation which brings a large background transmission and contrast ratio and that which gives an achromatic background color. So it is necessary to optimize the

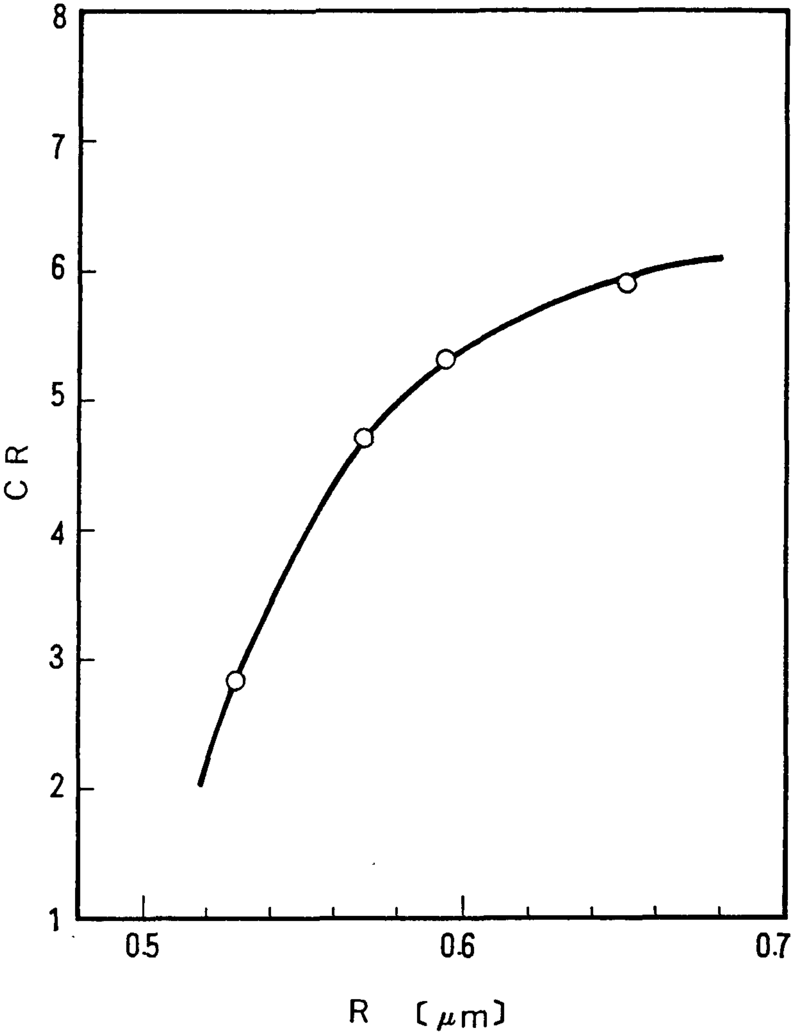

FIGURE 8 A retardation dependence of the contrast ratio CR when the optimum polarizer configuration is used for each retardation.

cell condition taking account of a balance between the background transmission, contrast ratio and background color. According to the experimental results, it is concluded that a retardation from 0.59 to 0.60 μm and polarizer configuration with Pr from −23 to −26 degrees and Pf from 50 to 52 degrees are optimum.

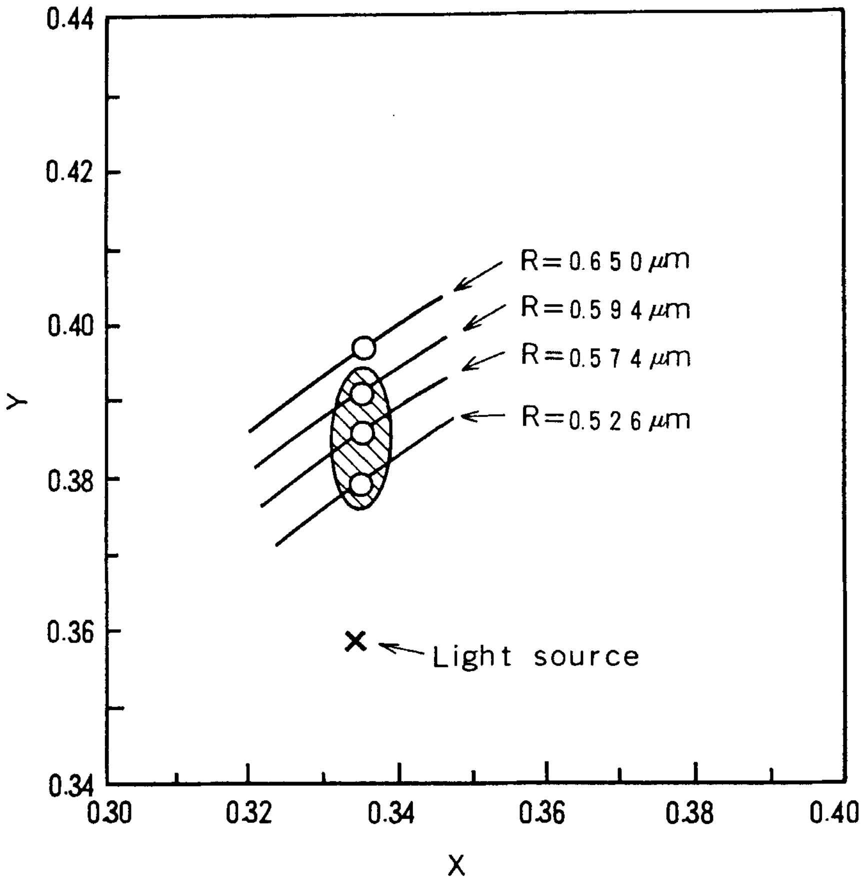

FIGURE 9 A change of the background color when the polarizer configuration is changed for each retardation. Circles correspond to the background color for the optimum polarizer configuration.

3. Development of LC Material

Performance of electro-optical characteristics of LC material was improved under the above-mentioned optimum condition of retardation and polarizer configuration. Characteristics such as sharpness, threshold voltage and response time were considered to be particularly important in the improvement. The contrast ratio under an actual multiplexing drive is thought to depend on the sharpness in electro-optical characteristics of LC material. It is necessary to decrease the threshold voltage of LC material due to a restriction of operating voltage of IC drivers used. And also, the response time is an important evaluation parameter.

Test cells using several LC materials whose birefringence Δn was from 0.089 to 0.091 were fabricated so that the retardation R becomes constantly about 0.59 μm. Electro-optical characteristics of the cells were measured with the optimum polarizer configuration. A representative electro-optical characteristics is shown in Figure 10. The sharpness γ and the threshold voltage V_{th} are defined as follows:

$$\gamma = (V_{40} - V_{90})/V_{90} \times 100\ [\%] \tag{4}$$

$$V_{th} = V_{90} \qquad [\text{volt}]. \tag{5}$$

In this definition, a transmission of a cell with no voltage application is defined as 100% and that with no light incidence to the detector is defined as 0%. An applied voltage at which the transmission becomes 90% is defined as V_{90} and that at which the transmission becomes 40% is defined as V_{40}.

A response time under a 1/200 duty multiplexing drive was measured changing the operating voltage. Response time τon and τoff were defined as the time required for the transmission to change to 90% of its final value when a waveform is changed from non-selected to selected waveform and from selected to non-selected waveform, respectively. As the response times τon and τoff change with a change of operating voltage, a response time when τon equals to τoff is used for a representative response time τ.

Table I shows evaluated values of sharpness γ, threshold voltage V_{th} and response time τ for several representative LC materials evaluated. As LC material LC-5 has a small γ, it is thought to bring with large contrast ratio even in a highly multiplexed drive. But a too large V_{th} of LC-5 is not acceptable. Although LC-6 has a small V_{th}, its γ value is so large that a good contrast ratio is not expected. Sharpness γ and threshold voltage V_{th} of LC-7 are satisfiable, but its too long response time is not acceptable. On the other hand, LC-8 is thought to be an excellent mixture in respect of sharpness, threshold voltage and response time.

4. DISPLAY PERFORMANCES OF THE ACHROMATIC ST LCD

An achromatic ST LCD with 640 × 400 pixels in an A4 page size and twist angle of 240 degrees which operates under a 1/200 duty

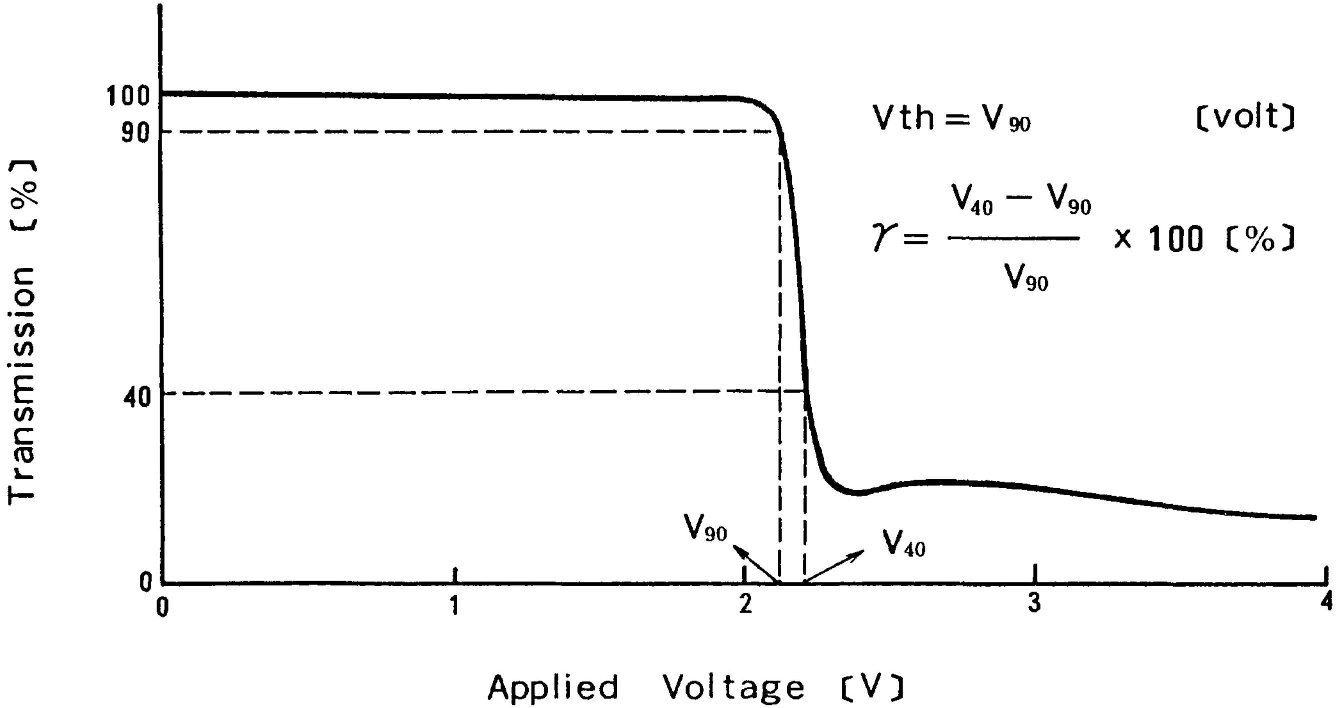

FIGURE 10 An example of electro-optical characteristics of an achromatic ST LCD.

TABLE I

Evaluated results of LC materials

LC material	Δn	d [μm]	Vth [volt]	γ [%]	τ [ms]
LCM-5	0.090	6.6	2.50	2.6	250
LCM-6	0.091	6.5	1.80	6.1	220
LCM-7	0.089	6.6	1.89	3.4	400
LCM-8	0.091	6.5	2.10	3.2	250

multiplexing drive was developed on the basis of the above-mentioned optimizations of the retardation, polarizer configuration and LC material. For a comparison, an achromatic ST LCD with a 180-degree twist angle and 0.512 μm retardation was fabricated. In the case of the 180-degree twist ST LCD, a LC material with birefringence of 0.093 and a cell thickness of 5.5 μm were adopted.[5] Polarizers were set so that the angle between their optical axis was 90 degrees and the absorption axis of the rear polarizer was parallel to the rear rubbing direction.

Chromaticity diagrams of the background colors of refrection type displays of the two kinds of the achromatic ST LCDs are shown in Figure 11. The figure also shows the background colors of a conventional TN LCD and an yellow mode ST LCD, whose twist angle is 240 degrees and the retardation is 0.75 μm. The background color of the achromatic ST LCD with a 240-degree twist angle is closer to the light source than that of the 180-degree twist ST LCD.

Table II shows display performances of the achromatic ST LCDs with twist angle of 240 and 180 degrees, the yellow mode ST LCD and TN LCD under a 1/200 duty multiplexing drive. In comparison between the ST LCDs, ST LCD with twist angle of 240 degrees has a larger contrast ratio and wider viewing angle than the 180-degree tiwst ST LCD. Although the response time of the 240-degree ST LCDs are longer than that of the 180-degree twist ST LCD, it is thought to be acceptable. In general, the larger the twist angle a ST LCD has, the larger the contrast ratio, the wider the viewing angle

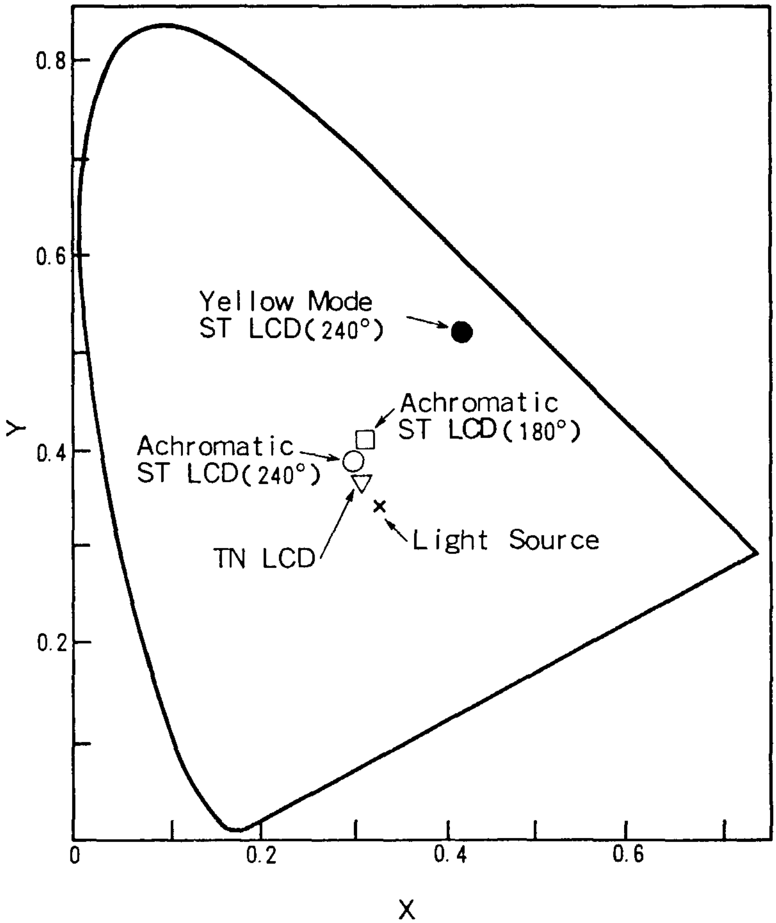

FIGURE 11 A CIE chromaticity diagram of the background color of each LCD.

and the longer the response time become. The achromatic ST LCD with twist angle of 240 degrees has an excellent display performances such as a high contrast ratio and wide viewing angle, though its contrast ratio is smaller than that of the yellow mode ST LCD. An example of displayed image of the achromatic ST LCD is shown in Figure 12.

5. CONCLUSIONS

Influences of retardation and polarizer configuration on background color, background brightness and contrast ratio have been studied

TABLE II

Display performances of various LCDs under a 1/200 duty multiplexing drive

	Achromatic ST LCD (240°twist)	Yellow mode ST LCD (240°twist)	Achromatic ST LCD (180°twist)	TN LCD
Color (display image/ background)	black / white	black / yellow	black / white	black / white
Contrast ratio (1/200 duty)	5 : 1	8 : 1	2.5 : 1	1.5 : 1
Viewing angle (1/200 duty)	−15° ~ 40°	−15° ~ 40°	0° ~ 40°	10° ~ 40°
Response time Ton / Toff (ms)	250 / 250	250 / 250	200 / 200	150 / 200

for a ST LCD with twist angle of 240 degrees. When the polarizer configuration is optimized for each retardation, a bright background and a high contrast ratio are obtained as the retardation is larger. On the other hand, the background color becomes more achromatic as the retardation is smaller. So it is necessary to optimize cell conditions taking account of a balance of the background brightness, contrast

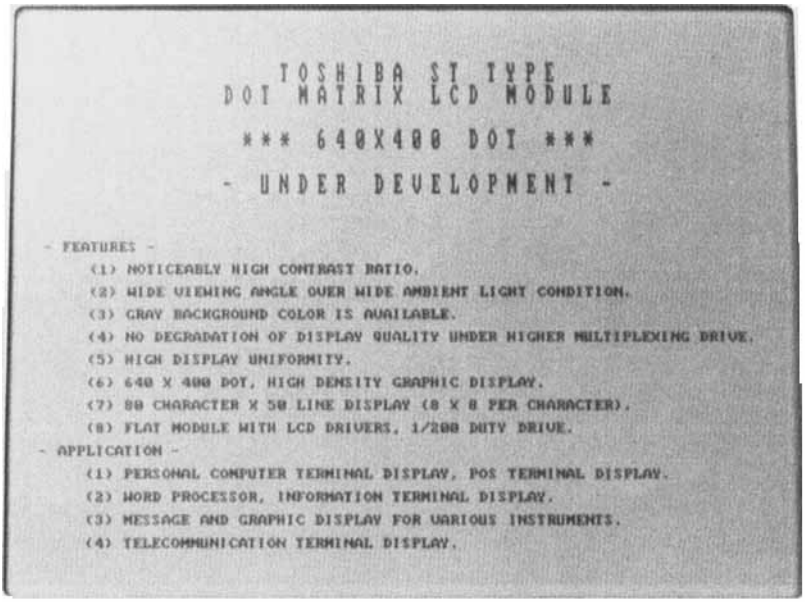

FIGURE 12 Photograph of the developed achromatic ST LCD with 640 × 400 pixels in an A4 size.

ratio and background color. It is concluded that the optimum retardation ranges from 0.59 to 0.60 μm and the optimum polarizer configuration for this retardation is Pr from −23 to −26 degrees and Pf from 50 to 52 degrees.

On the basis of the optimization of retardation, polarizer configuration and the LC material, an achromatic ST LCD with 640 × 400 pixels in an A4 page size and twist angle of 240 degrees which operates under a 1/200 duty multiplexing drive has been successfully developed. The achromatic ST LCD has an excellent display performances such as not only an achromatic background color almost the same as that of a conventional TN LCD but also a high contrast ratio and wide viewing angle.

Acknowledgments

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