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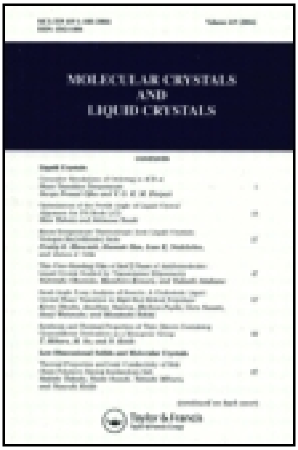

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The Effect of Various Parameters on TN-LCDs

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The Effect of Various Parameters on TN-LCDs

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The effects of pre-tilt angle θ_0, cell thickness d and optical anisotropy Δn are theoretically investigated, and the following results are obtained.

1) The pre-tilt angle θ_0 considerably affects multiplexability, i.e. threshold sharpness and viewing angle decrease with increase of θ_0.

2) Wider viewing angle can be obtained by smaller value of $\Delta n(550) \cdot d$, where $\Delta n(550)$ represents Δn at wavelength of 550 nm.

3) The condition free from the interference coloration is $\Delta n(550) \cdot d \geqslant 1.0\ \mu$m.

From these results, it is concluded that both $\theta_0 \simeq 0°$ (but $\theta_0 = 0°$) and $\Delta n(550) \cdot d \simeq 1.0\ \mu$m are suitable conditions for multiplex-driving.

1 INTRODUCTION

Twisted nematic liquid crystal devices (TN–LCDs) have been widely used because of their low driving voltage and their low power consumption. Recently, TN–LCDs are expected to be improved in multiplexability, and therefore it becomes important to suitably select the liquid crystal material and cell design parameters for multiplex-driving.

In this paper, the effects of cell design parameters of pre-tilt angle θ_0, cell thickness d and optical anisotropy Δn on multiplexed TN–LCDs are theoretically investigated. The electrooptic characteristics of TN–LCDs are calculated by following method. First, director configurations in the TN–LCDs at various applied voltage V_a are derived by using the Oseen–Frank elastic theory.[1,2] Then, using these director configurations, the propagation property of light through TN–LCD with crossed polarizer is calculated by Berreman's 4 × 4 matrix technique.[3,4]

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The transmission of TN–LCD depends on wavelength of transmissive light, so that the luminous transmittance should be generally used. But, it is confirmed that transmission at wavelength of 550 nm is almost the same with the luminous transmittance. Therefore, in this paper the characteristics of TN–LCDs are discussed by using transmission at the wavelength of 550 nm instead of luminous transmittance. On the other hand, electrooptical properties of TN–LCDs are affected by the value of optical anisotropy Δn and its dispersion in wavelength. However, it was confirmed in the previous paper that various liquid crystal materials with different Δn and its dispersion can be identically treated by using $\Delta n(550) \cdot d$,[5] which is the product of Δn at wavelength of 550 nm (denoted by $\Delta n(550)$) and the thickness of the liquid crystal layer.

2 ELECTROOPTIC CHARACTERISTICS OF TN-LCDs

$V_{10}(\alpha)$ and $V_{90}(\alpha)$ denote voltages corresponding to 10 % and 90 % change in transmission respectively for the incidence angle of α in the principal viewing plane which is defined as the plane containing normal of the substrate and the director in the middle of the liquid crystal layer (see Figure 1). Voltage is reduced by V_{th}, i.e. the theoretical threshold voltage at $\theta_0 = 0°$.

Figure 2 shows the dependence of θ_0 and $\Delta n(550) \cdot d$ on V_{10} (20°), V_{90} (20°). It is recognized from Figure 2 that both V_{10} (20°) and V_{90} (20°) decrease with increase of θ_0 and with decrease of $\Delta n(550) \cdot d$. The same result is obtained for different viewing angle α. This result indicates that multiplex-driving condition of a given liquid crystal material cannot be determined identically without considering θ_0 and d.

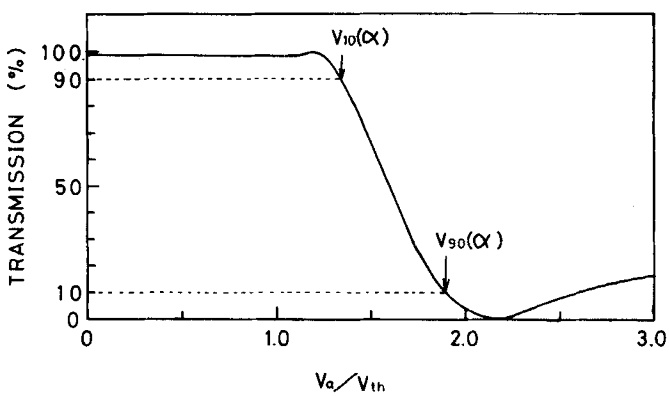

FIGURE 1 Definitions of $V_{10}(\alpha)$ and $V_{90}(\alpha)$.

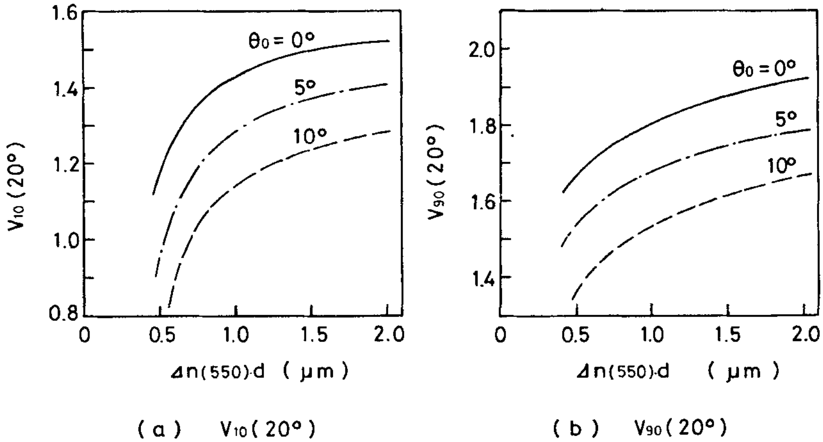

FIGURE 2. Dependence of $\Delta n(550) \cdot d$ and pretilt angle θ_0 on $V_{10}(20°)$ and $V_{90}(20°)$.

Table I shows the material constants used in the calculation, where K_{11}, K_{22}, K_{33} are the Oseen-Frank elastic constants for splay, twist, bend respectively, n_0 is ordinary reflective index, $\Delta\varepsilon(=\varepsilon_{\parallel} - \varepsilon_{\perp})$ is dielectric anisotropy, and $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are principal dielectric constants. These values except $\Delta\varepsilon/\varepsilon_{\perp}$ are of MBBA, supposing that MBBA is used as the host material. $\Delta\varepsilon/\varepsilon_{\perp}$ of 4.0 is taken as a typical value of the liquid crystal used in the TN–LCDs. It is confirmed that the similar result as shown in Figure 2 are obtained for other values of $\Delta\varepsilon/\varepsilon_{\perp}$, and that $\Delta\varepsilon/\varepsilon_{\perp}$ barely affects the other characteristics of TN–LCDs mentioned hereafter.

Figure 3 shows the dependence of θ_0 and $\Delta n(550) \cdot d$ on the threshold sharpness factor $V_{90}(20°)/V_{10}(20°)$ which denotes the sharpness of the electro-optic threshold at $\alpha = 20°$. Figure 4 (a), (b) shows the dependence of θ_0 and $\Delta n(550) \cdot d$ on the viewing angular factors V_{10} (0°)/V_{10} (40°) and V_{90} (0°)/V_{90} (40°), which indicate the measures of viewing angle dependence of V_{10} and V_{90} between $\alpha = 0°$ and $\alpha = 40°$. The sharpness factor V_{90} (20°)/V_{10} 20°) and the angular factors V_{10} (0°)/V_{10} (40°), V_{90} (0°)/V_{90} (40°) increase with

TABLE I

Material constants used in the calculation

Material constant	Value
K_{33}/K_{11}	1.22
K_{33}/K_{22}	2.05
$\Delta\varepsilon/\varepsilon_{\perp}$	4.00
n_0	1.54

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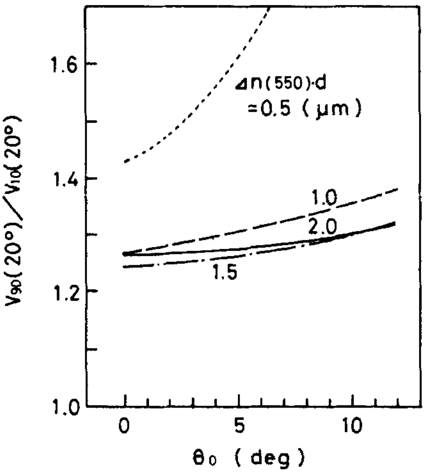

FIGURE 3 Dependence of θ_0 and $\Delta n(550) \cdot d$ on $V_{10}(20°)/V_{90}(20°)$.

increase of θ_0, which indicate the reduction of multiplexability of TN–LCDs. Especially, these tendencies are more conspicuous in the case of smaller values of $\Delta n(550) \cdot d$. Therefore, it is necessary to control θ_0 as small as possible for larger multiplexing.

The results of Figure 3 and 4 for $\theta_0 = 0°$ are summarized as follows.

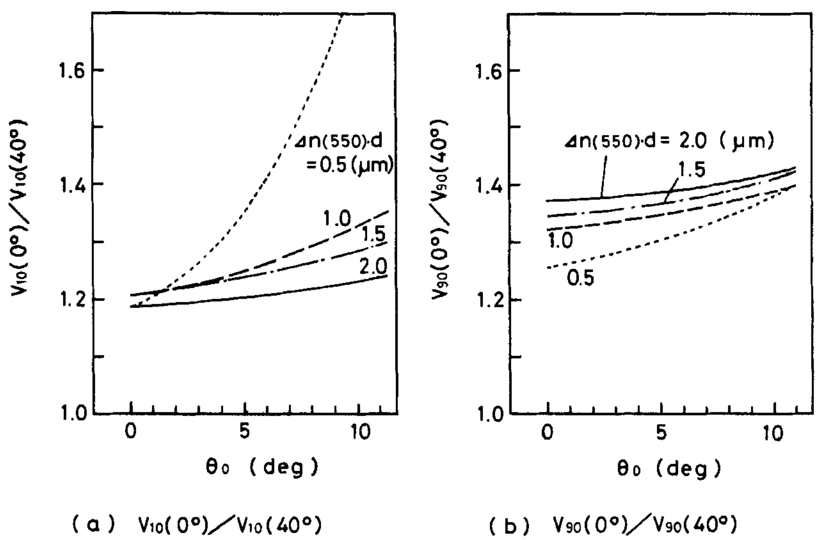

FIGURE 4 Dependence of θ_0 and $\Delta n(550) \cdot d$ on $V_{10}(0°)/V_{10}(40°)$ and $V_{90}(0°)/V_{90}(40°)$.

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1) Sharp threshold cannot be obtained in the case of $\Delta n(550) \cdot d \leqslant 1.0\ \mu m$.

2) The angular factor V_{10} (0°)/V_{10} (40°) barely depends on $\Delta n(550) \cdot d$.

3) The angular factor V_{90} (0°)/V_{90} (40°) decreases with decrease of Δn $(550) \cdot d$.

Considering these results, $\Delta n(550) \cdot d$ should generally be adjusted to 1.0 μm. In the case that wide viewing angle is required, however, $\Delta n(550) \cdot d$ should be adjusted smaller than 1.0 μm, though the sharp threshold cannot be expected.

3 COLORATION OF TN-LCDs

In order to improve the response of TN–LCDs and viewing angle, it is sometimes required to decrease the cell thickness d.[6] But an excess decrease of the cell thickness d induces interference coloration at off-state because of rotatory dispersion which is caused by conversion of the incident linearly polarized light into the eliptically polarized light. It is well known that the condition without the rotatory dispersion[7] is

$$\lambda/(4 \cdot \Delta n \cdot d) \ll 1, \tag{1}$$

where λ is the wavelength of incident light. But in actual, it is important to know the minimum value of cell thickness d. In this paper, the minimum value is investigated considering the detailed coloration of TN–LCDs by using 1931 CIE standard colorimetric system.

Figure 5 shows the dependence of $\Delta n \cdot d/\lambda$ on transmission for various values of θ_0 and α. Figure 6 shows the wavelength dependence on Δn of MBBA as an example. The luminous transmittance can be calculated by using the data of Figures 5 and 6. The results are shown in Figure 7 as a function of $\Delta n(550) \cdot d$. It is seen in Figure 7 that the luminous transmittances remarkably decrease when $\Delta n(550) \cdot d$ decreases smaller than 0.4 $\sim$ 0.5 μm. Therefore, $\Delta n(550) \cdot d$ must be larger than 0.4 $\sim$ 0.5 μm depending on θ_0.

On the other hand Figure 5 indicates that the transmission depends on the wavelength especially at smaller values of $\Delta n \cdot d/\lambda$, which means the coloration of the transmissive light. Then, the coloration was investigated by using the 1931 CIE chromaticity diagrams. Figure 8 shows the loci of the TN–LCDs in the CIE chromaticity diagrams as a function of $\Delta n(550) \cdot d$. The shape of these loci are similar to one another regardless of θ_0 or α through the location of $\Delta n(550) \cdot d$ on the locus depends on θ_0 and α. The locus of the chromaticity diagram can be divided into two regions, i.e. the rotating region around the neutral point W for example at $\Delta n(550) \cdot d \leqslant 1.0\ \mu m$ in Figure 8(a), and the radial region at $\Delta n(550) \cdot d \geqslant 1.0\ \mu m$ in the same figure. In the former region, the interference color depends on the thickness. Namely, irregularity of the

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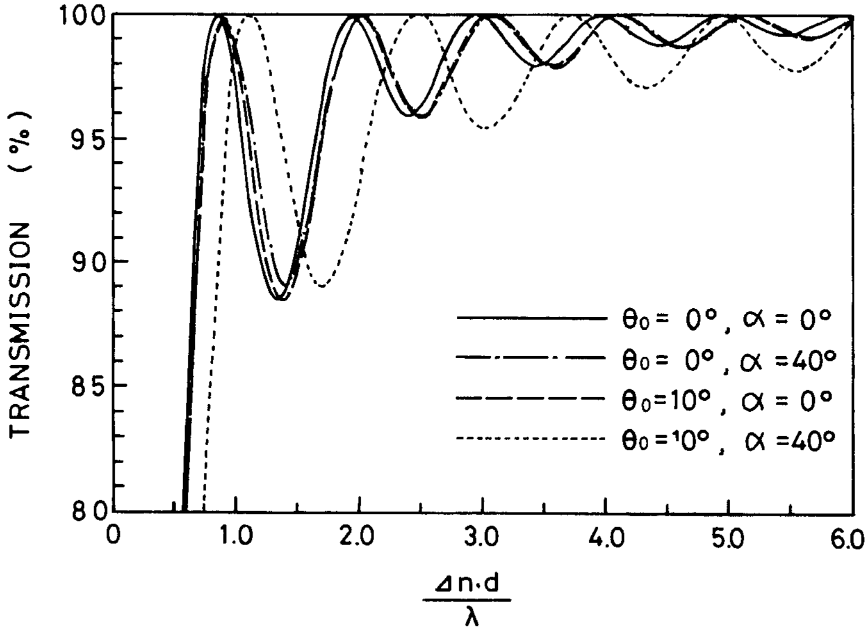

FIGURE 5 Dependence of $\Delta n \cdot d/\lambda$ on transmission for various combination of pretilt angle θ_0 and viewing angle α.

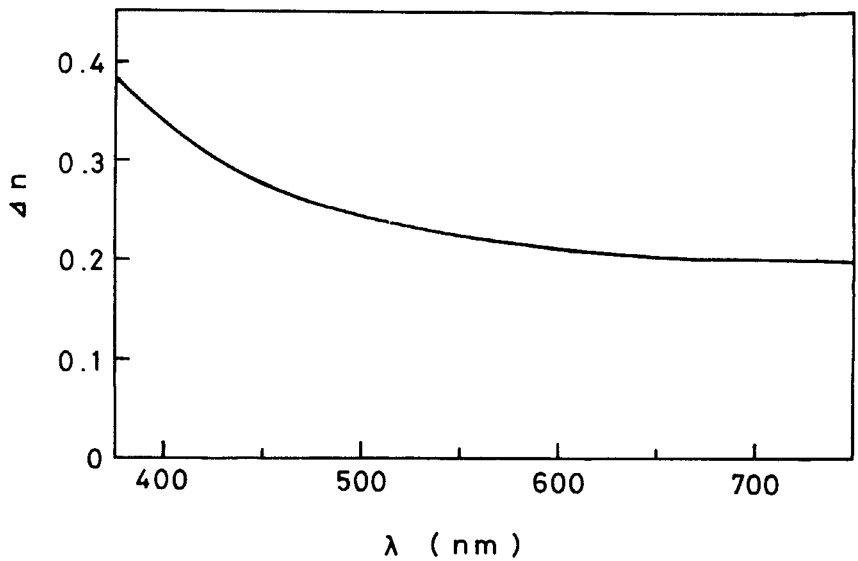

FIGURE 6 The wavelenth dependence on Δn of MBBA.

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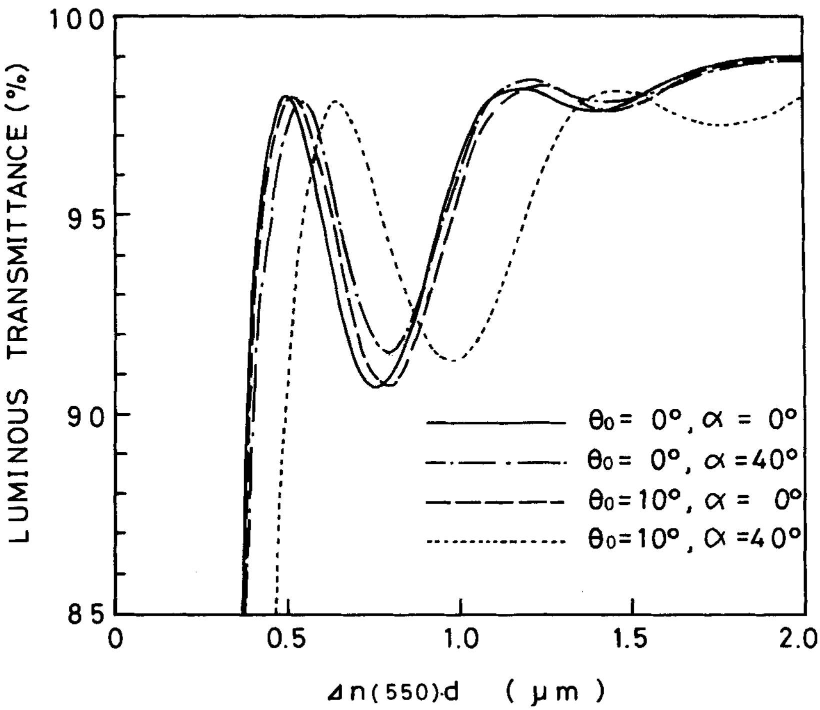

FIGURE 7 Dependence of $\Delta n(550) \cdot d$ on luminous transmittance.

cell thickness induces uneven interference colors. There is no such problem in the latter region except a slight change of the saturation of a pale color, which can be neglected. Therefore, the minimum of $\Delta n(550) \cdot d$ (referred to as $\{\Delta n(550) \cdot d\}_{min}$) is given by the value corresponding to the boundary position of the two regions in the locus of chromaticity diagram. When $\theta_0 = 0°$ and $\alpha = 0°$, for example, $\{\Delta n(550) \cdot d\}_{min}$ is given by 1.0 μm. Figure 9 shows the θ_0 and α dependence on $\{\Delta n(550) \cdot d\}_{min}$. It is known that the response and recovery time are proportional to the square of the cell thickness,[8] so that $\Delta n(550) \cdot d$ should be as small as possible. Therefore, it is seen from Figure 9 that $\theta_0 \approx 0°$ is preferable for obtaining small $\{\Delta n(550) \cdot d\}_{min}$ in the region of the viewing angle α of $0° \sim 40°$. In this condition, $\{\Delta n(550) \cdot d\}_{min}$ is 1.0 μm.

The interference coloration of the reflective mode of TN–LCDs can be also investigated in the same way. The calculation was made for the case of $\theta_0 = 0°$, and it is found that the shape of the locus in chromaticity diagram is the same as that of the transmissive mode except that the scale is twice in comparison with the transmissive one. In this reflective mode, $\{\Delta n(550) \cdot d\}_{min}$ is also given by 1.0 μm.

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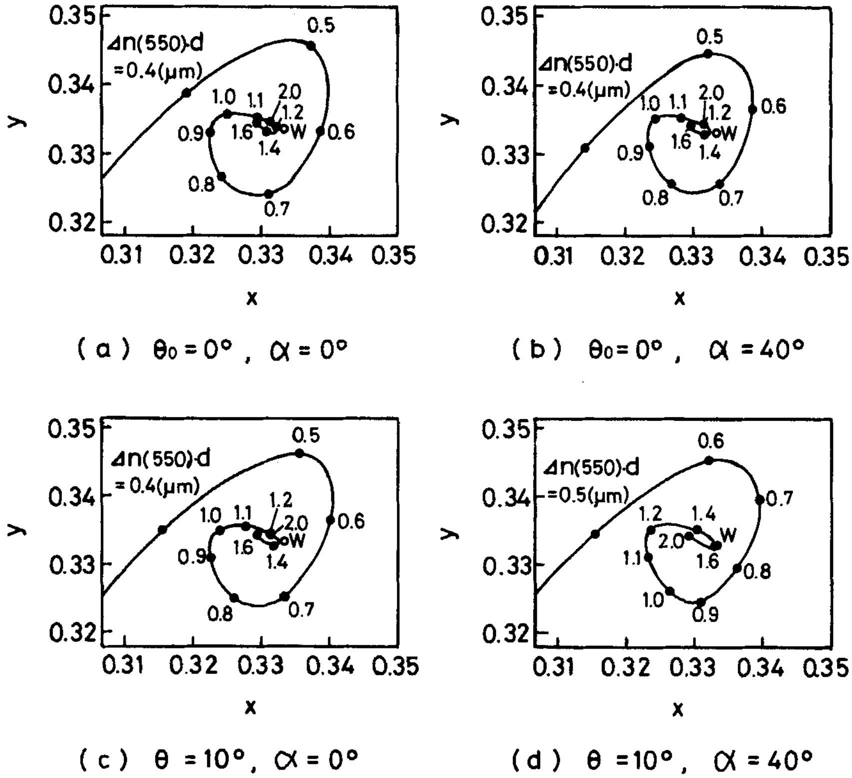

FIGURE 8 Locus in chromaticity diagram when $\Delta n(550) \cdot d$ in TN–LCD is changed.

The coloration of TN–LCDs with various kinds of liquid crystal materials are also investigated. Figure 10 shows the wavelength dependence of Δn of various liquid crystal materials (see Table II). Figure 11 shows the loci of chromaticity diagram obtained from Figure 10 when $\theta_0 = 0°$ and $\alpha = 0°$. Comparing Figure 11 (a)~(d) with Figure 8(a), it is seen that the shape of the loci and the locations of $\Delta n(550) \cdot d$ on the loci are similar to one another. It is confirmed from this result that $\{\Delta n(550) \cdot d\}_{min}$ is almost independent of the liquid crystal materials and is given by 1.0 μm.

4 CONCLUSION

Properties of TN–LCDs are calculated by Oseen–Frank elastic theory and Berreman's 4 × 4 matrix technique. Especially, the dependences of θ_0 and $\Delta n(550) \cdot d$ on the properties are investigated. The values of V_{10} (α) and

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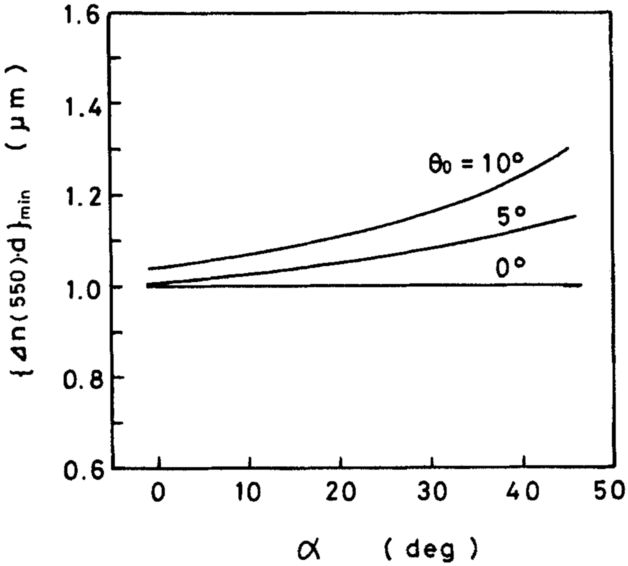

FIGURE 9 Dependence of α on $\{\Delta n(550)\cdot d\}_{\min}$.

TABLE II

Liquid crystal materials and their $\Delta n(550)$

Liquid crystal			$\Delta n(550)$
Azoxy compound	CH_3O-(O)-N=N(→O)-(O)-C_4H_9		0.273
Schiff base mixture	CH_3O-(O)-CH=N-(O)-C_4H_9	50 wt%	0.250
	C_2H_5O-(O)-CH=N-(O)-C_4H_9	35 wt%	
	C_2H_5O-(O)-CH=N-(O)-CN	15 wt%	
Biphenyl mixture	GR-41*)		0.253
PCH mixture	C_3H_7-(H)-(O)-CN	34 wt%	0.133
	C_5H_{11}-(H)-(O)-CN	34 wt%	
	C_7H_{15}-(H)-(O)-CN	32 wt%	

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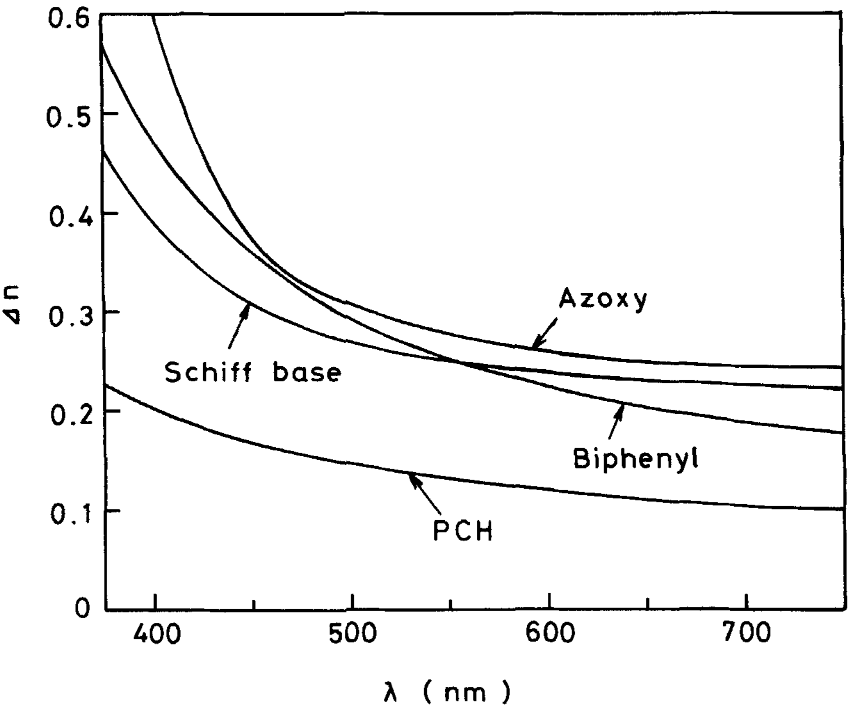

FIGURE 10 The wavelength dependence on Δn of various liquid crystal materials.

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V_{90} (α) considerably depends on θ_0 and $\Delta n(550) \cdot d$, so that multiplex-driving condition cannot be determined without considering both θ_0 and d. The threshold sharpness and viewing angle decrease with increase of θ_0. The minimum value of $\Delta n(550) \cdot d$ free from the interference coloration of TN–LCDs increases with increase of θ_0. That is, a large value of d is required in the case of a large θ_0 unless a liquid crystal with large $\Delta n(550)$ can be used. It is disadvantageous for obtaining fast response. Therefore, it is important to control θ_0 as small as possible. In this condition, the wider viewing angle can be obtained by smaller $\Delta n(550) \cdot d$. But an extremely small value of $\Delta n(550) \cdot d$ induces interference color. From the investigation on the coloration of TN–LCDs using CIE chromaticity diagram, it was confirmed that the minimum value of $\Delta n(550) \cdot d$ free from the interference coloration is given by 1.0 μm. Considering response time and viewing angle, it is concluded that $\Delta n(550) \cdot d$ should be adjusted to the minimum value of 1.0 μm.

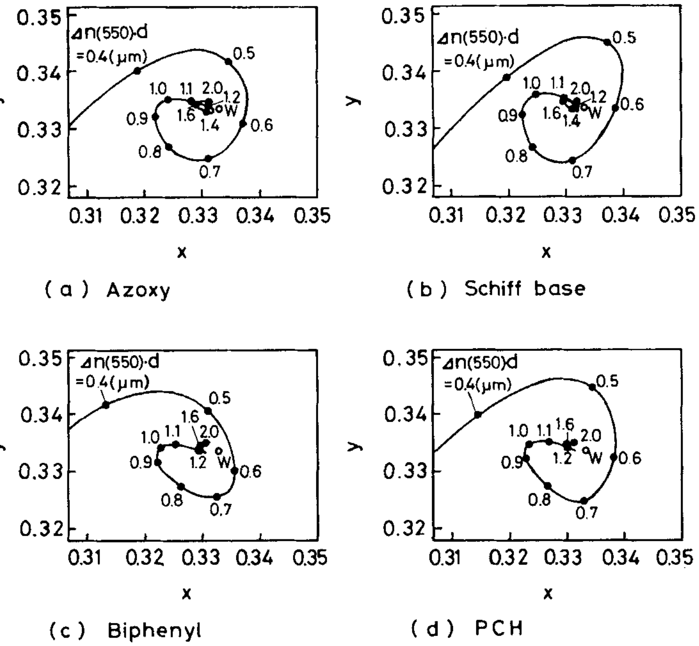

FIGURE 11 Locus in chromaticity diagram of various liquid crystal materials.

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