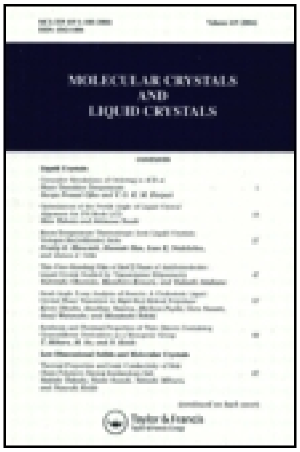

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The Effects of Material Constants and Device Parameters on Electrooptic Characteristics of Liquid Crystal Devices

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The Effects of Material Constants and Device Parameters on Electrooptic Characteristics of Liquid Crystal Devices

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The effects of liquid crystal (LC) material constants and cell parameters on electrooptic characteristics which control multiplexability of twisted nematic liquid crystal devices (TN-LCDs) were investigated on the basis of $\Delta nd/\lambda$ dependence. Computer simulations were carried out using Berreman's method, and some of the results were verified by experiments. Influence of dielectric and elastic constants on electrooptic characteristics were found to differ with Δnd, smaller $\Delta\epsilon/\epsilon_\perp$, K_{22}/K_{11} and K_{33}/K_{11} ratios gave smaller threshold sharpness. Only a small change in low pretilt angles was sufficient to produce a large effect on threshold sharpness. Electrooptic characteristics were significantly influence by changes in settings of the polarizer and analyzer.

1. INTRODUCTION

High quality TN-LCDs are in demand with advances in LC television and computer terminal displays, etc., which require high density of the dotted matrix cell, a large picture plane and high resolution pictures. Meeting these requirements calls for improved multiplexability which is mainly determined by the electrooptic characteristics. LC material constants, such as refractive indices n_e, n_o, dielectric constants $\epsilon_\parallel$, $\epsilon_\perp$,

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elastic constants K_{11}, K_{22}, K_{33} and cell parameters, such as cell gap d, pretilt angle α_0, the polarizer and analyzer, and wavelength of incident light source λ are factors that affect electrooptic characteristics. Here, n_e and n_o denote extraordinary and ordinary parts of the refractive indices; $\epsilon_{\parallel}$ and $\epsilon_{\perp}$ are the parallel and perpendicular parts of dielectric constants; and K_{11}, K_{22}, K_{33} denote elastic constants for splay, twist and bend, respectively. Optical and dielectrical anisotropy are defined as $\Delta n = n_e - n_o$ and $\Delta\epsilon = \epsilon_{\parallel} - \epsilon_{\perp}$, respectively.

Influence of LC material constants and cell parameters on the electrooptic characteristics have been investigated by both computer simulations and experiments,[1-6] but those studies were restricted to specific conditions, and it is difficult to generalize their results. On the other hand, influence of pretilt angle has been discussed using computer simulation for only a few Δnd values.[3,7] Some experiments have been reported on the effects of the polarizer and analyzer.[8,9] In this paper, we investigated the influence of these parameters on electrooptic characteristics based on $\Delta nd/\lambda$ dependence. Previous results were generalized and presented for use in LC device design. Computer simulations were carried out by using Berreman's method, with some of the results being verified by experiments.

2. CALCULATIONS

Light transmission curves are necessary for computer simulation in order to investigate the influence of various parameters on electrooptic characteristics. These curves were calculated by the following method. First, liquid crystal director configurations in the cell at various applied voltages were derived by solving problems of variation on energy, as given by continuum theory.[10-12] Second, light transmission was calculated under these configurations using Berreman's 4×4 matrix method.[13,14]

As shown in the light transmission curve of Figure 1, threshold sharpness r is defined as:

$$r = V_{50}(10°)/V_{th}(10°) \tag{1}$$

Here $V_{50}(10°)$ and $V_{th}(10°)$ (threshold voltage) denote applied voltages corresponding to 50% and 10% changes in transmission, respectively, at viewing angle of 10 degrees.

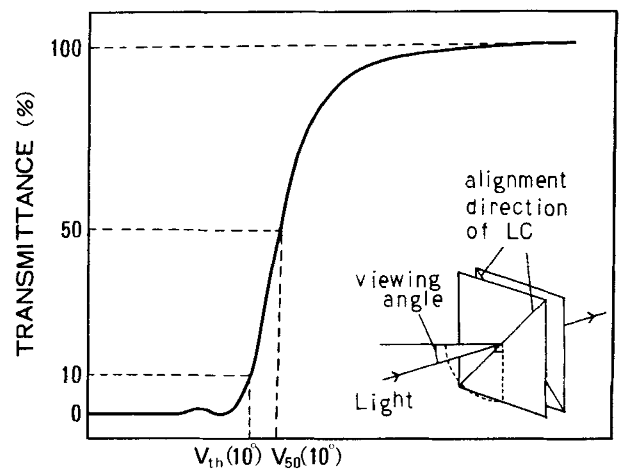

FIGURE 1 Light transmission curve.

3. EXPERIMENTAL

TN-LC cells with different cell gap (5–25 μm) were prepared for the experiments. Liquid Crystal ZLI-1800-000 (Merck Co.) having the material constants listed in Table I, was used and polyimide type polymer PIQ (Hitachi Chemical Co.) was used as a film for aligning the LC molecules.

The optical system used to measure electrooptic characteristics is shown in Figure 2. The light source used in this system had maximum intensity at about 550 nm. Gram–Thomson prism was used as the polarizer and analyzer. The applied voltage was 1 KHz pulse wave.

TABLE I

Material constants of LC used in experiments

dielectric constants	$\epsilon_{\parallel} = 11.1$ $\epsilon_{\perp} = 5.0$	$\Delta\epsilon/\epsilon_{\perp} = 1.22$
refractive indices	$n_e = 1.556$ $n_o = 1.480$	$\Delta n = 0.076$

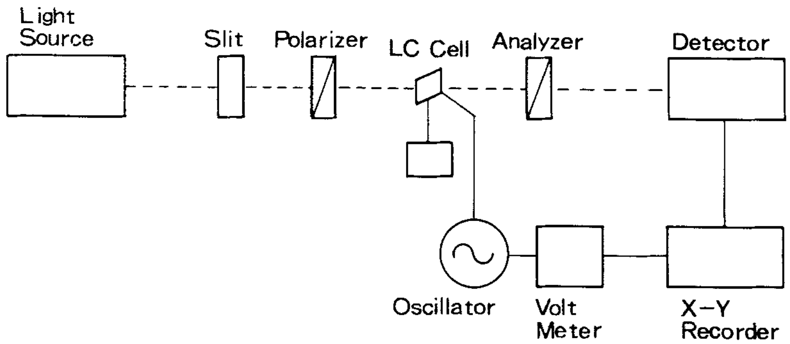

FIGURE 2 Optical system used in measurements.

4. RESULTS AND DISCUSSION

Liquid crystal material constants and device parameters used in the computer simulations are shown in Table II. Results will be shown by dependence on Δnd with the light source wavelength $\lambda = 550$ nm, for its suitability to LC cell design.

Influence of Material Constants

Dielectric constants influence the light transmission curve by parameter $\Delta\epsilon/\epsilon_{\perp}$. Simulation calculations were carried out for $\Delta\epsilon/\epsilon_{\perp} = 0.75$, 1.75, 3.2 with results shown in Figure 3. r showed a minimum value at $\Delta nd = 0.8$ μm and increased sharply for $\Delta nd < 0.8$ μm, but on the other hand $V_{th}(10°)$ decreased sharply over the same range. These tendencies were observed for all curves and were independent of

TABLE II

Material constants and device parameters used in calculations

elastic constants	K_{11}	1.1×10^{-11} N
	K_{22}	8.0×10^{-12} N
	K_{33}	1.6×10^{-11} N
dielectric constants	$\epsilon_{\parallel}$	9.9
	$\epsilon_{\perp}$	3.6
	$\Delta\epsilon/\epsilon_{\perp}$	1.75
pretilt angle	α_0	0.5
wavelength	λ	550 nm

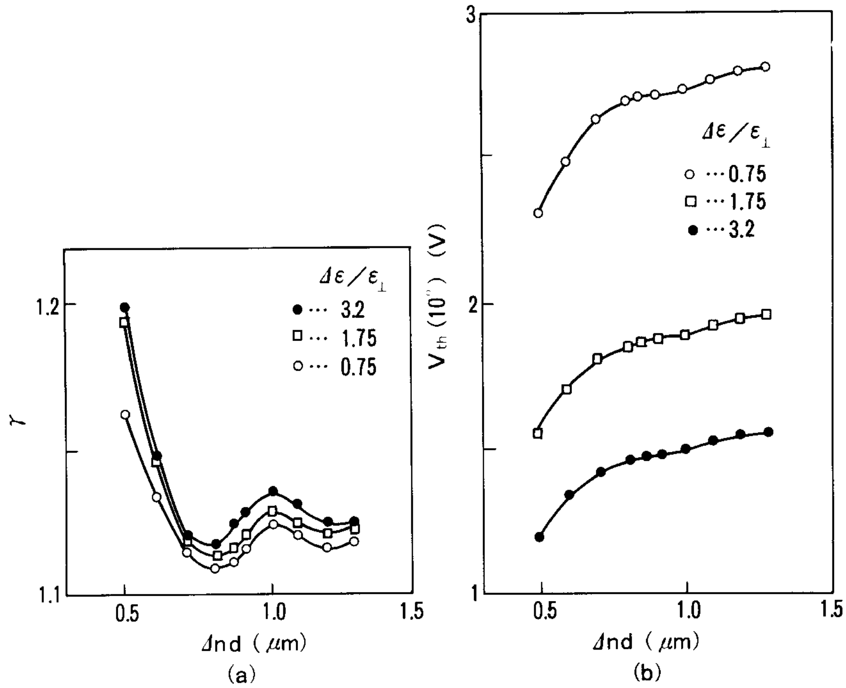

FIGURE 3 Influence of $\Delta\epsilon/\epsilon_\perp$ on r and $V_{th}(10°)$.

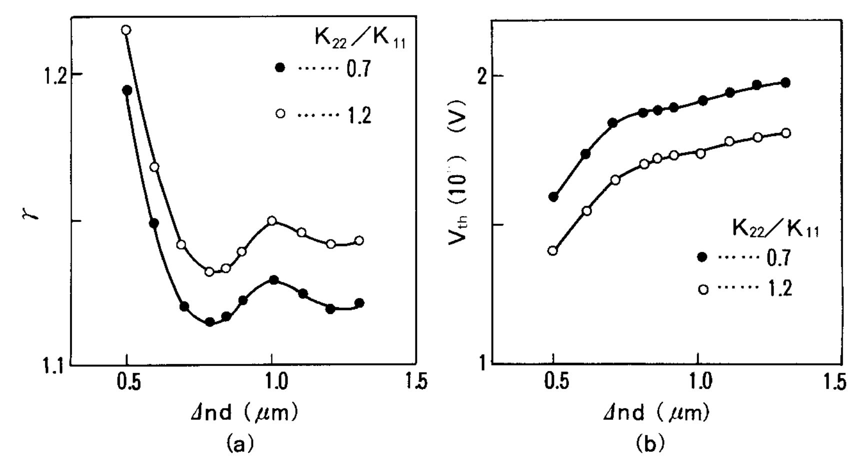

FIGURE 4 Influence of K_{22}/K_{11} on r and $V_{th}(10°)$.

$\Delta\epsilon/\epsilon_\perp$, but individual changes in value differed for each Δnd, especially at small Δnd values. For instance, when $\Delta\epsilon/\epsilon_\perp$ was changed from 3.2 to 0.75, r changed by 0.01 at $\Delta nd = 0.8$ μm while it changed by 0.04 at $\Delta nd = 0.5$ μm; that is, a smaller $\Delta\epsilon/\epsilon_\perp$ gave a smaller r, but its influence differed more with Δnd. Figure 3 also showed that the large change in $V_{th}(10°)$ placed a limit to decreasing $\Delta\epsilon/\epsilon_\perp$ in optimizing the LC cell design.

Influence of elastic constants on electrooptic characteristics depended on K_{22}/K_{11} and K_{33}/K_{11}, as shown in Figures 4 and 5. The curve patterns were independent of elastic constants. These figures showed that the influence of K_{22}/K_{11} on r and $V_{th}(10°)$ was almost independent of Δnd, while the influence of K_{33}/K_{11} depended on Δnd. For both factors, small K_{22}/K_{11} and K_{33}/K_{11} ratios gave a small r, but their effects on threshold voltage were not as much as for dielectric constants.

Influence of Cell Parameters

Influence of pretilt angle on electrooptic characteristics was examined at small angles, which are significant in LC cell design. Results are shown in Figure 6. Low pretilt angles gave a small r value, but the effect on threshold voltage was very small. Figure 6 also indicated that for the r value, the lowering pretilt angle for a couple of degrees corresponded to a large change in LC material constants. Low pretilt

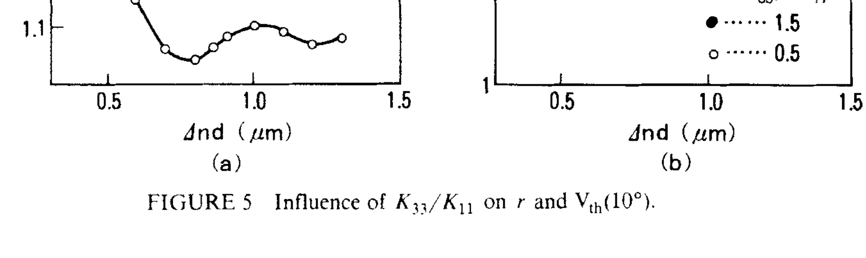

FIGURE 5 Influence of K_{33}/K_{11} on r and $V_{th}(10°)$.

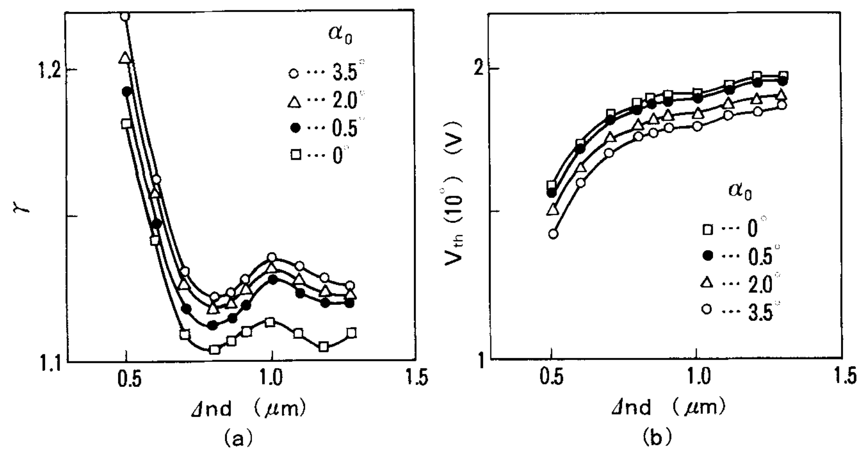

FIGURE 6 Influence of α_0 on r and $V_{th}(10°)$.

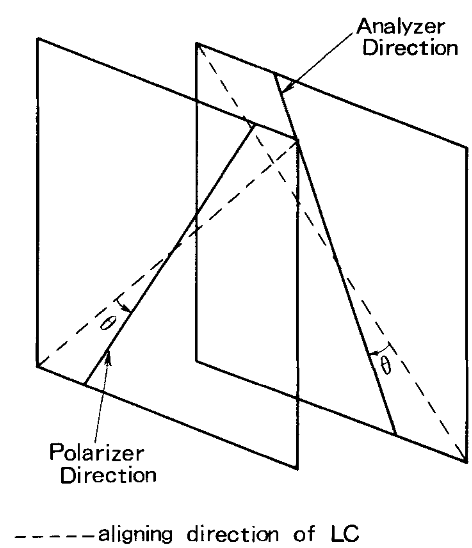

FIGURE 7 Setting of polarizer and analyzer.

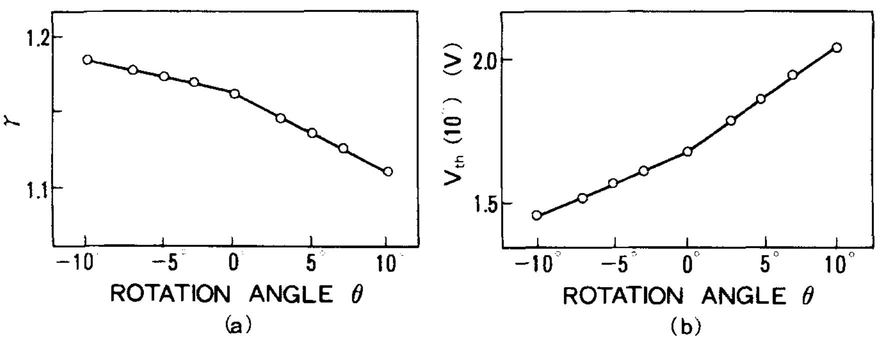

FIGURE 8 Influence of θ on r and $V_{th}(10°)$ ($\Delta nd = 0.57\ \mu m$).

angles can be achieved by designing the film for aligning LC molecules, independent of the choice of LC material.

The angle between the LC molecules and the polarizer or analyzer direction (hereafter rotation angle θ) affects light transmission characteristics. Calculations were carried out to examine this. Figure 7 shows the settings of the polarizer and analyzer with a variable θ. Influence of θ on electrooptic characteristics was calculated for $-10° < \theta < 10°$ with results plotted in Figure 8. r showed a noticeable linear decrease with increasing rotation angle. This indicated that rotation of the polarizer and analyzer was an effective way to enhance threshold sharpness. For LC devices, however, there is a limit on this, because of lowered contrast.[8,9]

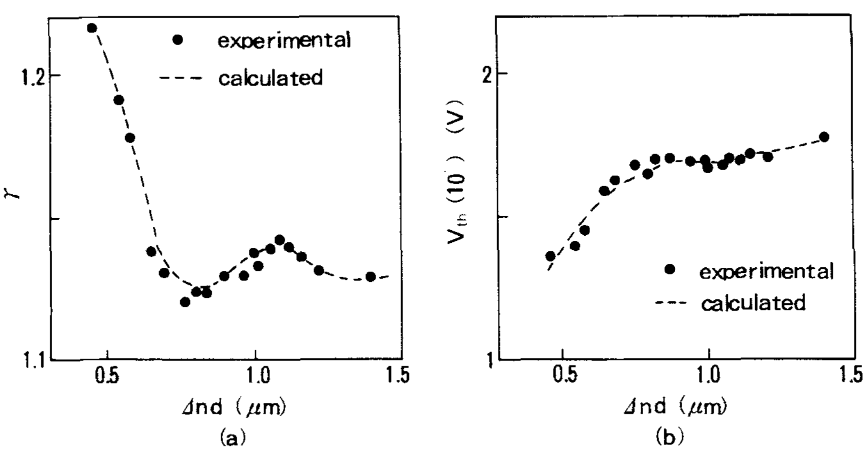

FIGURE 9 Δnd dependency of r and $V_{th}(10°)$.

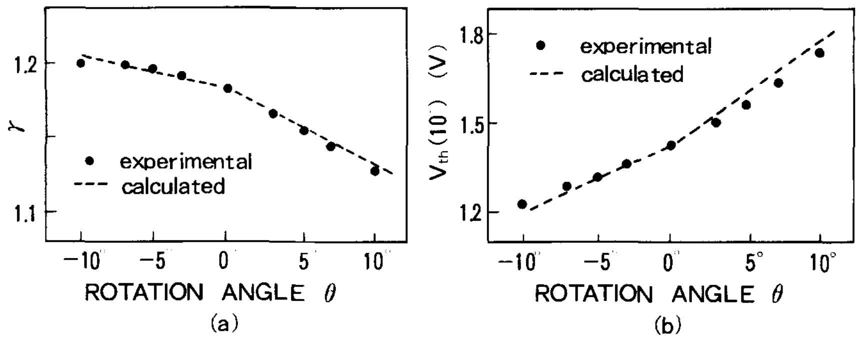

FIGURE 10 Influence of θ on r and $V_{th}(10°)$ ($\Delta nd = 0.57\ \mu m$).

Experiments

To verify the results obtained by simulation calculations, some experiments were performed. To examine Δnd dependency on electrooptic characteristics, we fixed all the factors considered, except cell gap d. Among the many methods available to measure pretilt angle,[16-19] we used the rotation method[16] because of its simplicity and preciseness, and it was 2.2° for these cells. The rotation angles of the polarizer and analyzer θ were taken as 0°, that is, the Twisted Nematic cell. The results are shown in Figure 9 with calculation curve of pretilt angle 2° by dotted line. The calculated value could not be strictly compared with experimental value, because elastic constants of the LC used in the experiments are unknown. But at least, Δnd dependence of r and $V_{th}(10°)$ can be considered to be verified by experiments, since curve patterns are very similar.

Experiments were also carried out for verification of the effects of polarizer and analyzer settings. A cell with $\Delta nd = 0.57\ \mu m$ was used to compare with the results obtained by calculation. The results are shown in Figure 10 with calculation curve by dotted line. Quite good agreement of these results indicates that these computer simulations are adequate.

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