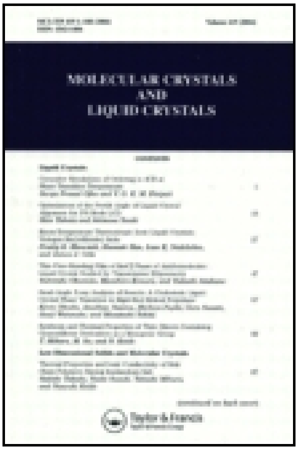

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Material and Cell Parameters Considerations in a Highly Multiplexing TN Liquid Crystal Display

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Material and Cell Parameters Considerations in a Highly Multiplexing TN Liquid Crystal Display†

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The LC material and cell parameters influence on such electro-optical characteristics as the steepness γ, viewing angle dependence β and threshold voltage V_{th} in a twisted nematic (TN) cell has been investigated.

The results have indicated the following:

(1) The steepest or smallest γ_{min} at some optimal cell thickness d_1 is reasonably estimated exclusively from the elastic constant ratio k_{33}/k_{11} of LC material.

(2) The steepness γ_{min} at the cell thickness d_1 is linearly decreased or definitely improved with decreasing the ratio k_{33}/k_{11}.

(3) The viewing angle dependence β has a maximum or the worst value at another cell thickness d_2 and is effectively improved with decreasing the cell thickness d in the region $d < d_2$.

(4) The threshold voltage V_{th} is reduced with decreasing d in the region below another cell thickness d_3, which is different from d_1 and d_2.

Through the optimization of LC material and cell parameters based on the above results, a 12-inch diagonal highly multiplexing dot-matrix TN LCD with 640 × 200 pixels has been successfully developed, which displays sophisticated graphic patterns as well as 25 lines by 80 characters with good legibility.

1. INTRODUCTION

Liquid crystal display (LCD) must be truly the most successful information display among recent electronic display devices.[1] Never-

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theless, in case of LCD, a multiplexing capability is not sufficient, which is required to achieve a large information display. Thus, a lot of attempts are being made to improve the capability, applying the various modes of LCD. Especially, a considerable development emphasis is now laid on realization of a highly multiplexing dot-matrix twisted nematic liquid crystal display (TN LCD), which has a large information content and a large display area comparable to those of a CRT display.

Main fundamental electro-optical characteristics in a TN cell, which essentially determine the multiplexing capability, are the steepness (γ), viewing angle dependence (β) and threshold voltage (V_{th}); the number of multiplexable lines, width of viewing angle and operating voltage directly depend on the values of γ, β and V_{th}, respectively.

In this paper, the influence of LC material and cell parameters on the above-mentioned electro-optical characteristics has been studied. Such material and cell parameters considerations have led to successful development of a 12-inch diagonal highly multiplexing dot-matrix TN LCD with 640 × 200 pixels, which displays sophisticated graphic patterns as well as 25 lines by 80 characters in an 8 × 8 dot format. Figure 1 and Table I show the external appearance and performance/mechanical characteristics of the multiplexing dot-matrix TN LCD.[2]

2. EXPERIMENTAL

The nematic LC mixtures used were multicomponent LC blends with a relatively large positive dielectric anisotropy $\Delta\epsilon$ as well as a small bend to splay elastic constant ratio k_{33}/k_{11}. The LC blends comprised such polar and nonpolar nematic LC components as are shown later in Tables III and IV. The measured material parameters of the representative three kinds of LC blends are given in Table II. The LC blends T-10, T-20 and T-30 belonged to dioxane/phenylcyclohexane, pyrimidine/cyclohexyl ester and dioxane/phenyl ester mixed classes, respectively.

The electro-optical response in a TN cell was measured as a function of cell thickness d and light incident angle, *i.e.*, a viewing angle ϕ, using light from a halogen lamp compensated for a luminosity factor and applying a 32 Hz sq. wave voltage. The TN cell with a twist angle 90° was prepared by sandwiching each LC blend between rubbed polymer-coated electrode substrates and placed under crossed polarizers. All measurements were carried out at 25°C.

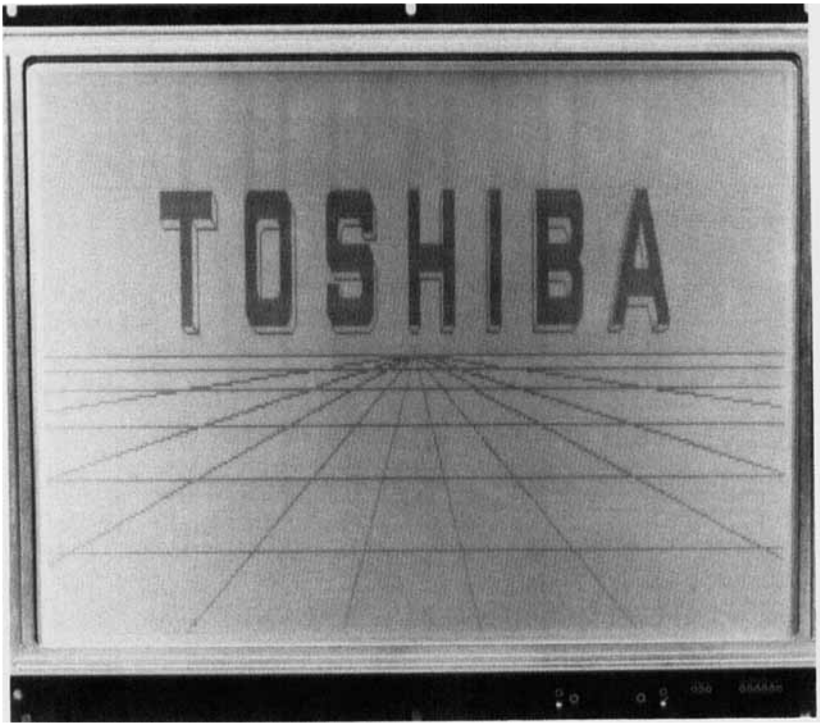


FIGURE 1 External appearance of the 12-inch diagonal multiplexing dot-matrix TN LCD with 640 × 200 pixels.

TABLE I

Performance and mechanical characteristics of the multiplexing dot-matrix TN LCD.

Items		Typical characteristics
Performance	Contrast ratio (CR)	7 : 1 (Maximum)
	Viewing angle	15° ~ 35° (CR > 3 : 1)
	Response times	250 m sec (on) / 250 m sec (off)
Mechanical	Number of dots	640 (Horizontal) x 200 (Vertical)
	Number of characters	2000 (= 25 lines by 80 characters)
	Display area	252 (W) x 191 (H) mm² (12″ diagonal)
	Dot size	0.33 (W) x 0.812 (H) mm²
	Outline dimension	274.8 (W) x 240.6 (H) x 24.0 (D) mm²

TABLE II

Material parameters of the representative LC blends used in the experiments.

LC blend	Nematic range (°C)	Δn	η (cp)	$\Delta\varepsilon$	k_{33}/k_{11}
T-10	<-20 ~ +67	0.123	21	+7.5	0.99
T-20	-26 ~ +66	0.098	35	+4.5	0.88
T-30	<-20 ~ +62	0.141	52	+5.9	0.91

3. RESULTS AND DISCUSSION

3.1 Cell thickness *d* influence on steepness γ

In Figures 2 and 3, the measured steepness γ is plotted as a function of cell thickness d for two kinds of TN cells filled with LC blends T-10 and T-20, together with the calculated relation of γ vs. d. The measured γ value was obtained from the electro-optical response curve of a TN cell, using the following equation:

$$\gamma[\%] = \frac{V(T = 50\%, \phi = 0°) - V(T = 90\%, \phi = 0°)}{V(T = 90\%, \phi = 0°)} \times 100, \tag{1}$$

where $V(T = 90\%, \phi = 0°)$ and $V(T = 50\%, \phi = 0°)$ are the applied voltages at which the transmission T reaches 90% and 50%, respectively, at vertical light incidence to the cell, *i.e.*, at a viewing angle $\phi = 0°$.

According to the definition of the steepness γ by Eq. (1), the smaller the γ value is, the higher the multiplexibility in a TN cell becomes, *i.e.*, the more the number of multiplexable lines.

The calculated relation curve, on the other hand, was obtained by inserting the material parameters k_{33}/k_{11} and Δn given in Table II into the following Schadt & Gerber semiempirical equation for the steepness γ at a viewing angle $\phi = 0°$ [3]:

$$\gamma[\%] = 13.30 + 2.66(k_{33}/k_{11} - 1) + 44.3\,[\ln(\Delta n \cdot d/2\lambda)]^2, \tag{2}$$

where λ is the wavelength of 550 nm.

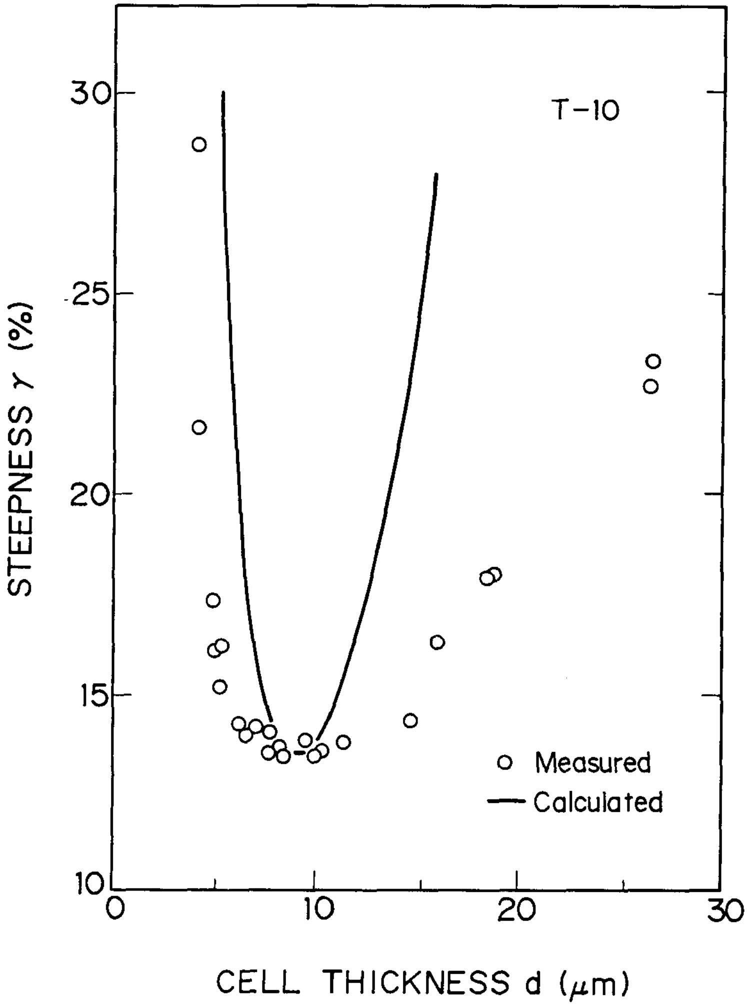


FIGURE 2 Measured and calculated relation of the steepness γ vs. the cell thickness d for a TN cell T-10.

According to the experimentally plotted results, γ has the minimum or steepest value (hereinafter, denoted as γ_{min}) at some cell thickness d_1 in both cases of T-10 and T-20 cells. This is not only qualitatively consistent with the relationship expected from Eq. (2), but also the experimental absolute values of γ_{min} and d_1 themselves are well coincident with the calculated γ_{min} and d_1 values, derived from the condition $\Delta n \cdot d/2\lambda = 1$; the calculated γ_{min} is 13.2% at $d_1 = 8.9$ μm and 12.9% at $d_1 = 11.2$ μm for T-10 and T-20 TN cells, respectively.

Such good coincidence definitely indicates that the steepest value

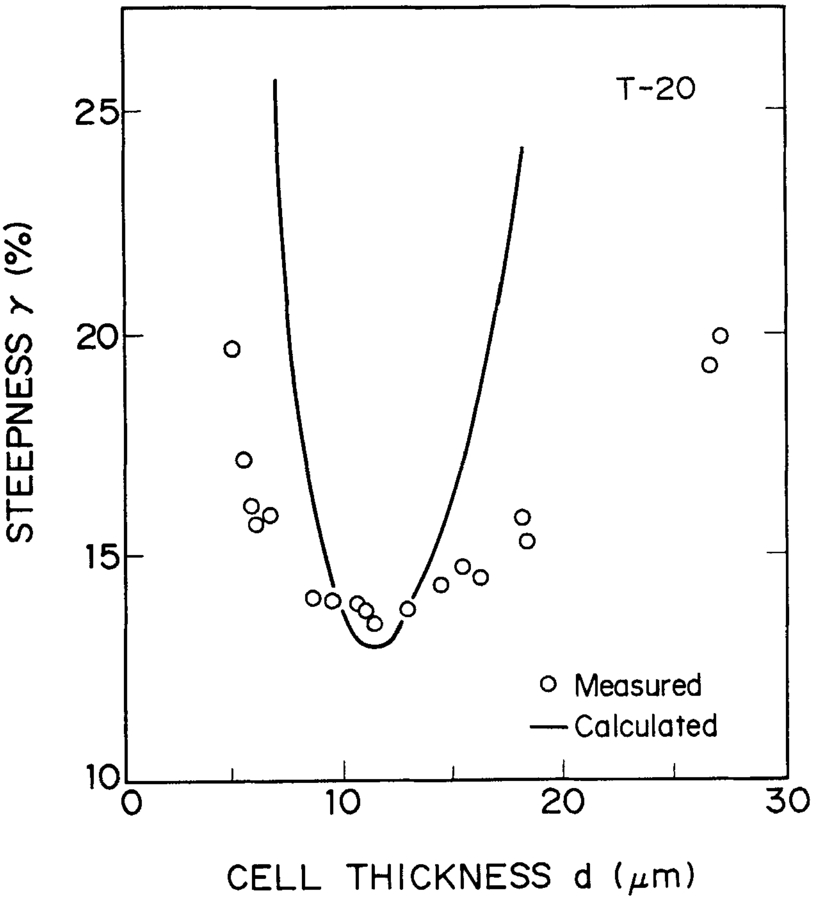


FIGURE 3 Measured and calculated relation of the steepness γ vs. the cell thickness d for a TN cell T-20.

γ_{min} at some optimal cell thickness d_1 can be reasonably estimated exclusively from the elastic constant ratio k_{33}/k_{11} of LC material, by using Eq. (2).

Incidentally, it is noteworthy that a considerable deviation of the calculated γ_{min} from the observed one is found at the cell thickness far from d_1, especially in the region $d > d_1$. The deviation may suggest the necessity for some modification of Eq. (2).

3.2 Elastic constant ratio k_{33}/k_{11} influence on steepness γ

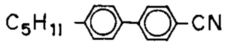
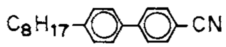
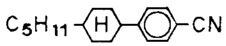
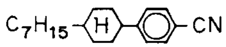
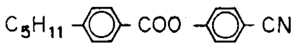
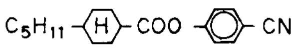
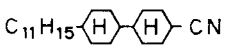
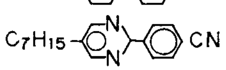
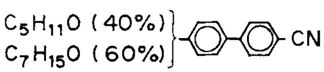
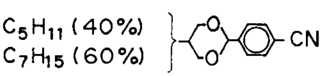
In order to elucidate more definitely the influence of the elastic constant ratio k_{33}/k_{11} on the steepness γ, multicomponent LC blends with $k_{33}/k_{11} = 0.74 \sim 1.27$ were prepared, which comprised such polar and nonpolar nematic LC components as are representatively shown in Tables III and IV, respectively.

Nonpolar nematic components having dialkyl and alkyl/alkoxy terminal groups with a small dipole moment generally have a smaller k_{33}/k_{11} ratio, compared with polar components having a cyano terminal group with a strong dipole moment. However, the dielectric anisotropy $\Delta\epsilon$ of the nonpolar components usually has a very small positive or negative value. Therefore, the blending of polar and nonpolar components is required to achieve an optimal LC mixture, at least, with a reasonable $\Delta\epsilon$ value or practically acceptable operating voltage for a multiplexing TN LCD.

In Figure 4, the γ_{min} value measured from the relation of γ vs. d in TN cells filled with the above LC blends is plotted as a function of k_{33}/k_{11}, together with the corresponding relationship calculated from Eq. (2). The measured relation of γ_{min} vs. k_{33}/k_{11} agrees well

TABLE III

Representative polar nematic LC components with a relatively large elastic constant ratio k_{33}/k_{11}.

LC component	k_{33}/k_{11}	Meas.Temp.	Reference
	1.24	$T = T_C - 5$ (°C)	P. Karat, et.al.
	1.08		
	1.80	$T = 0.95 T_C$ (K)	Hp. Schad, et.al.
	1.63		
	1.70		M. Osman, et.al.
	1.68		
	1.21		
	0.94		
	1.24	$T = T_C - 10$ (°C)	M. Schadt, et.al.
	1.43		

within $\gamma_{min} = \pm 0.8\%$ with the calculated one in the relatively wide range of k_{33}/k_{11}. This agreement strongly supports that the steepness γ_{min} in a TN cell is definitely improved or linearly decreased with decreasing the ratio k_{33}/k_{11} of LC material, under the condition fulfilling $\Delta n \cdot d = 2\lambda$.

Nevertheless, this means also that the improvement in the steepness γ_{min} has a definite limitation, since the γ value can never be expected which is smaller or steeper than the smallest limit of $\gamma = 10.64\%$, calculated from Eq. (2) on the assumption of $k_{33}/k_{11} = 0$ and $\Delta n \cdot d = 2\lambda$. The steepness $\gamma = 10.64\%$ just corresponds to the maximum number of multiplexable lines $N_{max} = 98.5$ in a TN LCD at a viewing angle $\phi = 0°$, which is estimated from the following Alt and Pleshko relation of N_{max} vs. γ in a multiplexing TN LCD[4]:

$$N_{max} = \left[\frac{(1 + \gamma/100)^2 + 1)}{(1 + \gamma/100)^2 - 1)}\right]^2. \qquad (3)$$

TABLE IV

Representative nonpolar nematic LC components with a relatively small elastic constant ratio k_{33}/k_{11}.

LC component	k_{33} / k_{11}	Meas.Temp	Reference
CH_3O -⟨◯⟩- COO -⟨◯⟩- C_5H_{11}	1.43	T = 0.95 T_C (K)	M. Osman, et. al.
C_5H_{11} -⟨H⟩- COO -⟨◯⟩- CH_3	1.05		
C_5H_{11} -⟨H⟩- COO -⟨◯⟩- C_5H_{11}	0.77		B. Scheuble, et. al.
C_5H_{11} -⟨H⟩- COO -⟨◯⟩- OCH_3	1.20		M. Osman, et. al.
C_5H_{11} -⟨H⟩- COO -⟨◯⟩- OC_4H_9	0.90		M. Scheuble, et. al.
C_5H_{11} -⟨pyrimidine N,N⟩-⟨◯⟩- OC_5H_{11}	0.91		
C_6H_{13} -⟨pyrimidine N,N⟩-⟨◯⟩- OC_6H_{13}	0.71		
C_6H_{13} -⟨pyrimidine N,N⟩-⟨◯⟩- OC_9H_{19}	0.56		
C_5H_{11} -⟨bicyclooctane⟩- COO -⟨◯⟩- C_5H_{11}	1.03		
C_5H_{11} -⟨H⟩- COO -⟨◯(F)⟩- C_5H_{11}	1.12		
C_5H_{11} -⟨dioxane O,O⟩-⟨◯⟩- {OC_2H_5 (40%), OC_4H_9 (60%)}	0.85	T = T_C − 10 (°C)	M. Schadt, et. al.

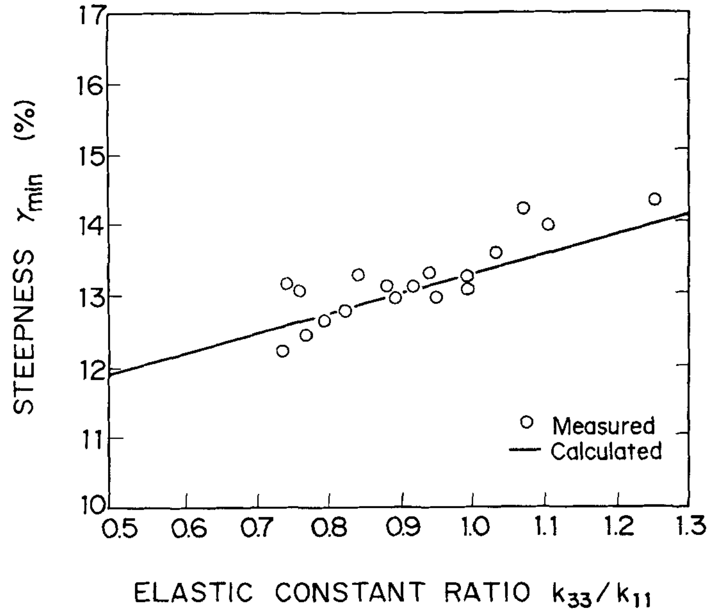


FIGURE 4 Measured and calculated relation of the steepness γ vs. the elastic constant ratio k_{33}/k_{11}.

3.3 Viewing angle ϕ influence on steepness γ

Figure 5 gives the viewing angle ϕ dependence of an electro-optical response curve for a TN cell filled with a LC blend T-30, together with the steepness γ values measured from each curve. The results show that the steepness γ is remarkably improved with increasing the viewing angle.

Such improvement leads to the effective increase of multiplexable lines in a TN LCD. Specifically, the steepness $\gamma = 13.1\%$ at $\phi = 0°$ is decreased to $\gamma = 8.7\%$ at such a viewing angle $\phi = 25°$ as is practically adopted in most LCD applications. According to Eq. (3), the γ value 8.7% can realize the multiplexing lines of 144.4, which is much more than the calculated upper limit of multiplexable lines 98.5 described in the preceding section.

3.4 Cell thickness *d* influence on viewing angle dependence β

As represented in Figure 5, the electro-optical response curve greatly depends on the viewing angle ϕ. Here, the following parameter β is introduced to describe the degree of the viewing angle dependence:

$$\beta(\%) = \frac{V(T = 90\%, \phi = 0°) - V(T = 90\%, \phi = 40°)}{(1/2)[V(T = 90\%, \phi = 0°) + V(T = 90\%, \phi = 40°)]}, \quad (4)$$

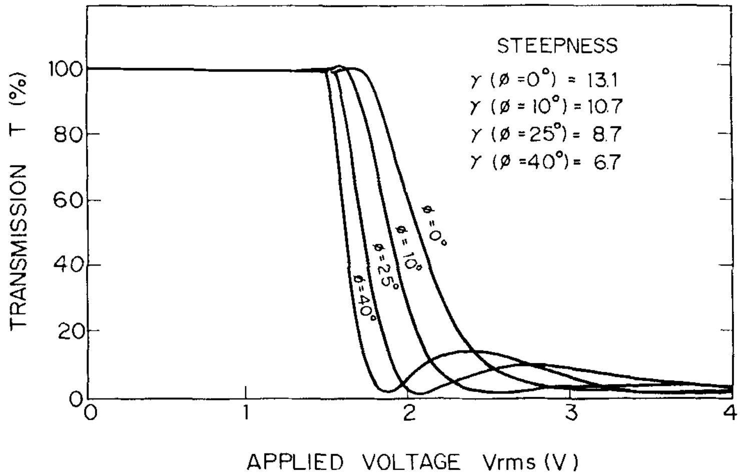


FIGURE 5 Measured dependence of the electro-optical response curve on the viewing angle φ for a TN cell T-30.

where V(T = 90%, φ = 0°) and V(T = 90%, φ = 40°) are the voltages at which the transmission T reaches 90% at the viewing angle φ = 0° and 40°, respectively. The smaller the parameter β is, the wider the viewing angle in a TN LCD becomes.

Figure 6 shows measurements of the viewing angle dependence β as a function of the cell thickness d for T-10 and T-20 TN cells. The β value becomes maximum at some cell thickness $d_2 \simeq 20$ μm and greatly decreases in the region below and above d_2 for both cells, although their maximum β values differ by about 5%.

These results mean that the viewing angle of a TN LCD is effectively improved with decreasing the cell thickness d or the cell retardation $R = \Delta n \cdot d$, in the region of a practically adopted cell thickness around 10 μm. This is well consistent with the suggestion based on the Baur's model calculation[5] that the viewing angle dependence in a TN LCD may be reduced by decreasing the birefringence Δn of LC material.

3.5 Cell thickness *d* influence on threshold voltage V_{th}

Figure 7 presents measurements of the threshold voltage V_{th} of electro-optical response, defined as V(T = 90%, φ = 0°), vs. the cell thickness d for T-10 and T-20 TN cells. In both cases, V_{th} decreases with decreasing the cell thickness below some cell thickness $d_3 \simeq 15$ μm and remains nearly constant in the region $d > d_3$, although the absolute V_{th} value in each cell differs not a little.

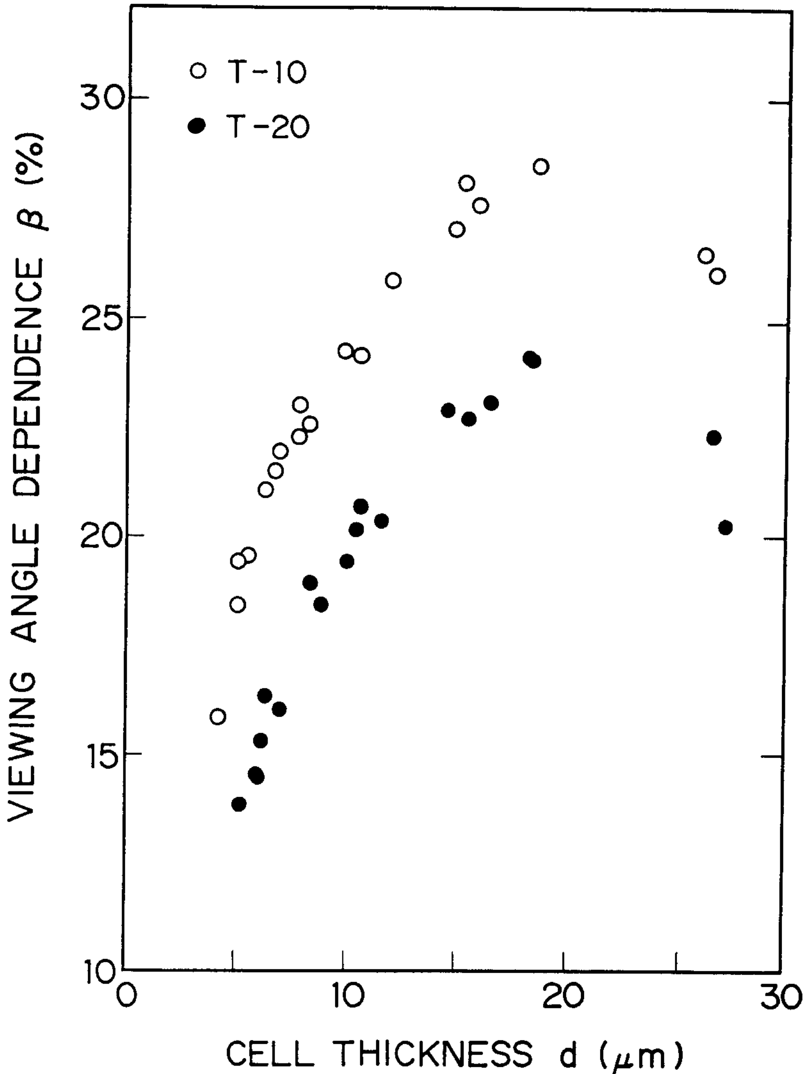


FIGURE 6 Measured relation of the viewing angle dependence β vs. the cell thickness *d* for TN cells T-10 and T-20.

These results indicate that the decrease of cell thickness effectively reduces the operating voltage in a TN LCD. Such decrease is especially required in a highly multiplexing TN LCD. The reason is that the rms driving voltage V_{rms} is inevitably decreased with increasing the number of multiplexing lines N in a TN LCD, since the maximum

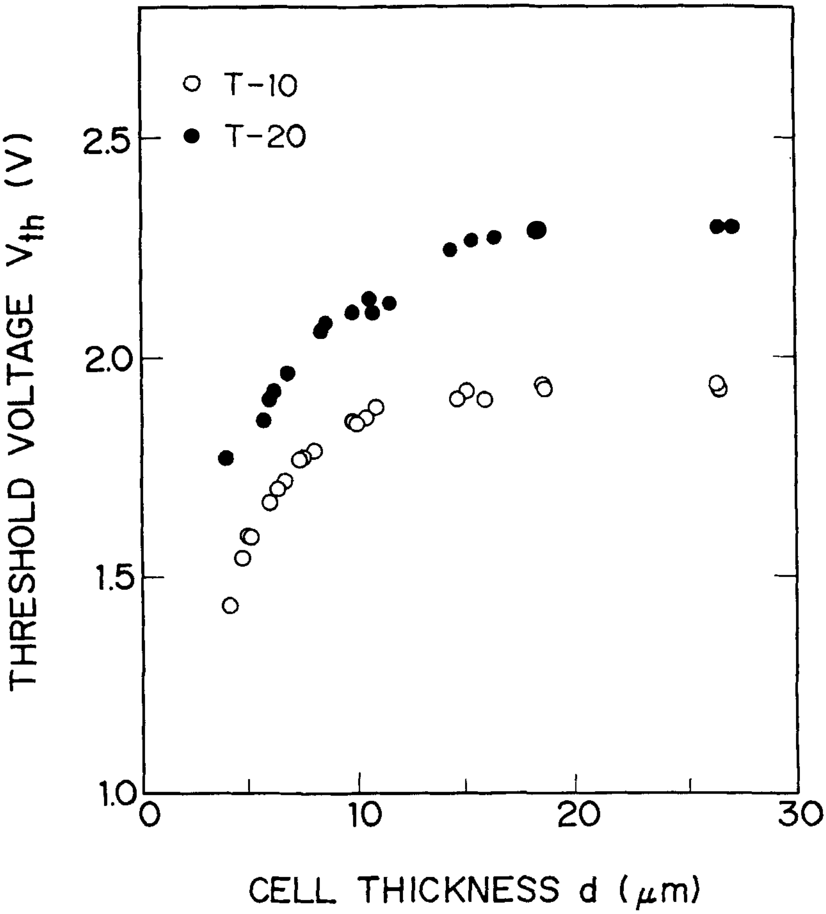


FIGURE 7 Measured relation of the threshold voltage V_{th} vs. the cell thickness *d* for TN cells T-10 and T-20.

peak voltage supplied by driving electronics is practically limited and fixed. For example, the available maximum V_{rms} values in the cases of $N = 64$, 100 and 200 decrease by the ratio of 1:0.83:0.61.

4. CONCLUSIONS

In order to realize a highly multiplexing twisted nematic liquid crystal display (TN LCD), the LC material and cell parameters influence on such electro-optical characteristics as the steepness γ, viewing angle dependence β and threshold voltage V_{th} in a TN cell, which determine essentially the multiplexing capability of TN LCD, has been investigated.

The results have indicated the following:

(1) The steepest or smallest γ_{min} at some optimal cell thickness d_1 is reasonably estimated exclusively from the elastic constant ratio k_{33}/k_{11} of LC material, using the Schadt & Gerber equation.

(2) The steepness γ_{min} at the cell thickness d_1 is definitely improved or linearly decreased with decreasing the ratio k_{33}/k_{11}.

(3) The viewing angle dependence β has a maximum or the worst value at another cell thickness d_2 and is effectively improved with decreasing the cell thickness d in the region $d < d_2$.

(4) The threshold voltage V_{th} is reduced with decreasing d in the region below some cell thickness d_3, which is different from both values d_1 and d_2, whereas V_{th} becomes constant above d_3.

Through the optimization of LC material and cell parameters based on the above results, a 12-inch diagonal highly multiplexing dot-matrix TN LCD with 640 × 200 pixels has been successfully developed, which displays sophisticated graphic patterns as well as 25 lines by 80 characters and has such practically acceptable display performance as the contrast ratio 7:1, viewing angle 15° ~ 35° and response times 250 msec.

Acknowledgments

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