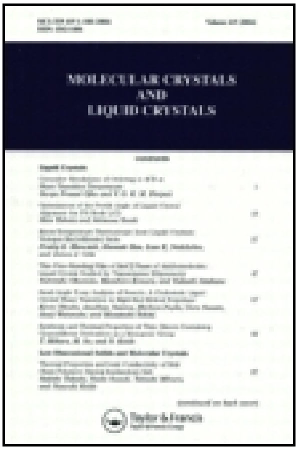

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Effects of Nematic Compounds with High Clearing Points on the Multiplexing Performance of Twisted Nematic Displays

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Effects of Nematic Compounds with High Clearing Points on the Multiplexing Performance of Twisted Nematic Displays

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The addition of nematic compounds with high clearing points (N_h) to multiplexable nematic liquid crystals decreases the temperature dependence of the threshold voltage of twisted nematic displays. This effect depends on the dielectric anisotropy of the nematic liquid crystals containing N_h, as well as on the increase in T_c. In the case of 4-*n*-butylphenyl 4′-(4″-butylbenzoyloxy) benzoate, the low threshold voltage was exceptionally compatible with a small temperature dependence of threshold voltage, and this result was attributed to the large temperature dependence of the dielectric anisotropy in comparison with that of nematic liquid crystals containing other N_h's.

INTRODUCTION

Recently, twisted nematic displays (TN–LCD's) have been gaining popularity in battery-driven instruments such as watches and calculators, and much effort has been devoted to improve the multiplexability of TN–LCD's.

Multiplexability of TN–LCD's is determined by the physical properties of the nematic liquid crystals (NLC's). Numerous patents concerning multiplexable NLC's have been issued. However, design rules have not yet been established, because the physical properties of all the nematic compounds in use are not sufficiently well characterised, and the estimation of physical properties is very complicated for mixtures.

Paper presented at the 8th International Liquid Crystal Conference, Kyoto, Japan, June 30–July 4, 1980.

It has been reported that NLC's which consist of N_n and N_p are suitable for multiplexing.[1] N_n means NLC's having negative dielectric anisotropies and N_p corresponds to materials with positive dielectric anisotropies.

Furthermore, the addition of high clearing point nematics (N_h), such as terphenyls and biphenylcyclohexanes, categorised as compounds containing more than three rings, has been found to have a pronounced effect on multiplexability of NLC's.

In this paper, multiplexable NLC's containing several N_h compounds have been made to evaluate the effects of the N_h components on the temperature dependence of the threshold voltage. The material dependence was studied in terms of clearing points, dielectric anisotropy, and elastic constants.

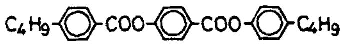
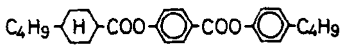
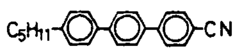
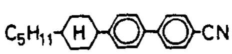
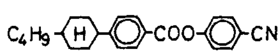
EXPERIMENTAL

1 Materials

Table I shows the N_h compounds used, together with their thermal properties, such as melting point (T_m), clearing point (T_c), and heat of fusion (ΔH).

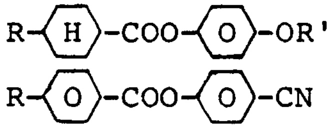
TABLE I

Thermal properties of N_h compounds

Structure		T_m (°C)	T_c (°C)	ΔH (kcal/mol)
	(PBB)	88	180	3.9
	(PHB)	63	193	7.5
	(T15)	131	240	4.1
	(BCH)	95	219	4.4
	(S1225)	107	226	6.2

4-*n*-butylphenyl 4′-(4″-butylbenzoyloxy)benzoate(PBB) and 4-*n*-butylphenyl 4′-(*trans*-4″-butylcyclohexylcarbonyloxy)benzoate(PHB) were synthesized according to literature methods.[2,3] Other N_h compounds were commercially available.

The compositions of the NLC's were as follows.



N_n	80 pts
N_p	20
N_h	5.3 ~ 17.6

For electro-optical measurements, a small amount of cholesteryl nonanoate (less than 0.1 parts by wt.) was added to avoid reverse-twist. The concentration of cholesteryl nonanoate was sufficiently small to have essentially no influence on the electro-optic properties.

2 Measurements of dielectric, elastic, and electro-optic properties

The electro-optic properties of a TN cell were measured under the following conditions.

- cell thickness: 8 μm for the electro-optical measurements
  50 μm for the dielectric and elastic measurements
- twist angle : 90°
- tilt angle : $<1^\circ$

Electro-optic properties were measured with the configuration shown in Figure 1(a). is in the main viewing direction determined by the direction of orientation of the liquid crystal molecules.

Figure 1(b) shows the definition of the voltages which are measured by a 100 Hz sin wave. Curve *a* depicts the temperature dependence of the voltage which causes a 50% transmission change at $\theta = 10^\circ$. Similarly, curve *b* corresponds to the condition $\theta = 10^\circ$, 10% transmission, and curve *c* to the condition $\theta = 40^\circ$, 10% transmission.

Dielectric and elastic constants of NLC's were obtained from capacitance *versus* voltage curves, using a phase sensitive detection technique.[4] The measuring signal was 1.5 KHz, 28 mVrms sin wave, and the bias voltage was a 150 Hz sin wave. The sweep rate of the bias voltage was less than 8×10^{-5} V/sec.

3 Expressions of multiplexability of TN-LCD's

Three parameters were defined using the voltages shown in Figure 1(b).

sharpness (s_T)

$$s_T = \frac{V(T, 10, 50)}{V(T, 10, 10)}$$

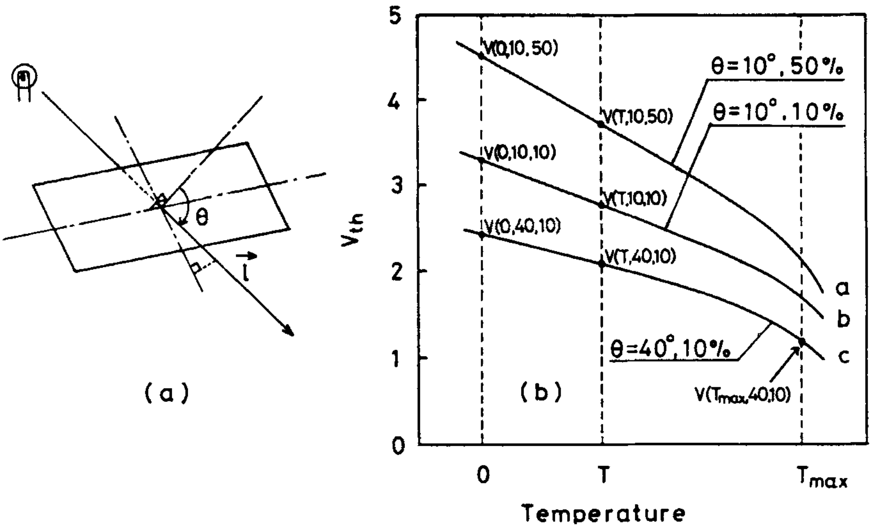


FIGURE 1 (a) Measuring configuration. l is in the main viewing direction. (b) Definition of threshold voltages.

angular dependence (q_T)

$$q_T = \frac{\{V(T, 10, 10) - V(T, 40, 10)\}}{V(T, 10, 10)}$$

temperature dependence (t)

$$t = \frac{\{V(0, 40, 10) - V(T_{\max}, 40, 10)\}}{V(0, 40, 10)}$$

Figures of merit were defined as follows:

at one temperature;

$$m \equiv \alpha \cdot \frac{V(T, 40, 10)}{V(T, 10, 50)} = \frac{\alpha(1 - q_T)}{s_T},$$

over the temperature range from 0°C to $T_{\max}$;

$$M \equiv \alpha \cdot \frac{V(T_{\max}, 40, 10)}{V(0, 10, 50)} = \frac{\alpha(1 - q_0)(1 - t)}{s_0} \tag{2}$$

where α is a wave-form factor determined by the duty ratio, bias voltage, and frequency.

In practice, driving voltage margins can be expressed as follows using these figures of merit:

at one temperature;

$$m' \equiv \frac{\alpha V(T, 10, 50) - V(T, 40, 10)}{\frac{1}{2}\{\alpha V(T, 10, 50) + V(T, 40, 10)\}} \times 100$$

$$= \frac{2(m - 1)}{m + 1} \times 100\,(\%), \tag{3}$$

over the temperature range from 0°C to $T_{\max}$;

$$M' = \frac{\alpha V(0, 10, 50) - V(T_{\max}, 40, 10)}{\frac{1}{2}\{\alpha V(0, 10, 50) - V(T_{\max}, 40, 10)\}} \times 100$$

$$= \frac{2(M - 1)}{M + 1} \times 100\,(\%). \tag{4}$$

RESULTS AND DISCUSSION

Figure 2 shows the PBB concentration dependence of M/α, m/α and T_c. M/α and m/α, which are defined only by the voltages, are more appropriate expressions to characterise nematic compounds.

It can be seen that m/α was nearly independent of PBB concentration whilst, on the other hand, M/α was strongly dependent on PBB concentration. This is due to the decrease in temperature dependence with the addition of PBB.

Figure 3(a) shows the $T_{\max}$ dependence of t in NLC's containing 10% of N_h. Material dependence was observed for the N_h compounds used, and PBB was the most effective among them. From Figure 2, it can be seen that t decreases with the increase in T_c. Hence, $T_{\max}$ should be normalised by T_c to evaluate the effect of N_h. Figure 3(b) shows the relation between $1 - t$ and $T_{\max}/T_c$. Only in the case of PBB was the temperature dependence improved. The NLC containing PHB was almost equivalent to the NLC without N_h. On the other hand, NLC's containing $T15$, BCH, and $S1225$ were rather inferior to the NLC without N_h.

The increase in T_c by the addition of H_h's brings about a decrease in temperature dependence of the order parameter in an operating temperature range, and thus the addition of N_h cases the decrease in t. However the material dependence shown in Figure 3(b) cannot be explained only by the increase in T_c.

The effect of the dielectric anisotropies ($\Delta\varepsilon$) of the NLC's containing N_h on the t values was considered. Figure 4 shows the relation between t and the threshold voltage of the capacitance (V_c). V_c was nearly proportional to

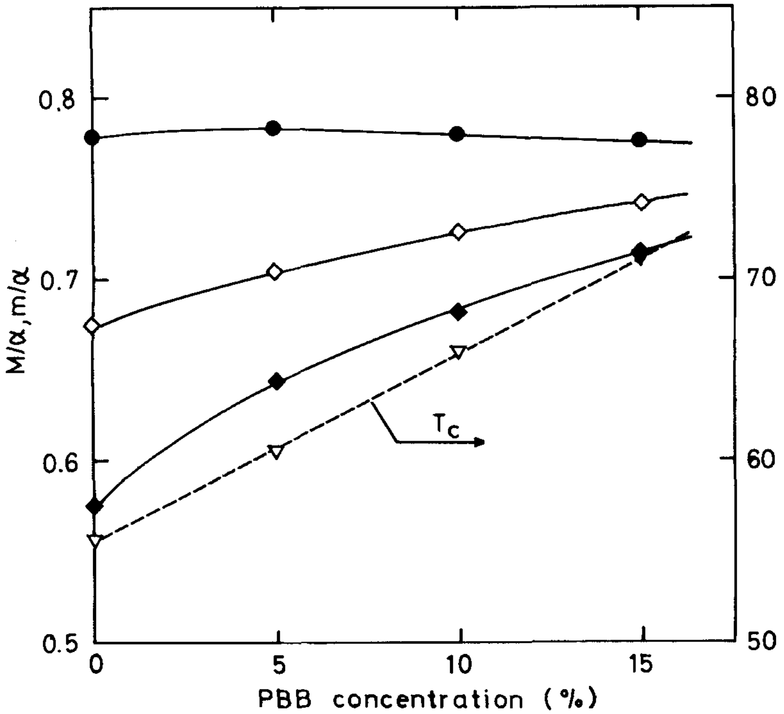


FIGURE 2 PBB concentration dependence of voltage margins and clearing point. ● m_0 25°C. M_0 (0 ~ 40°C). M_0 (0 ~ 50°C). clearing point (T_c).

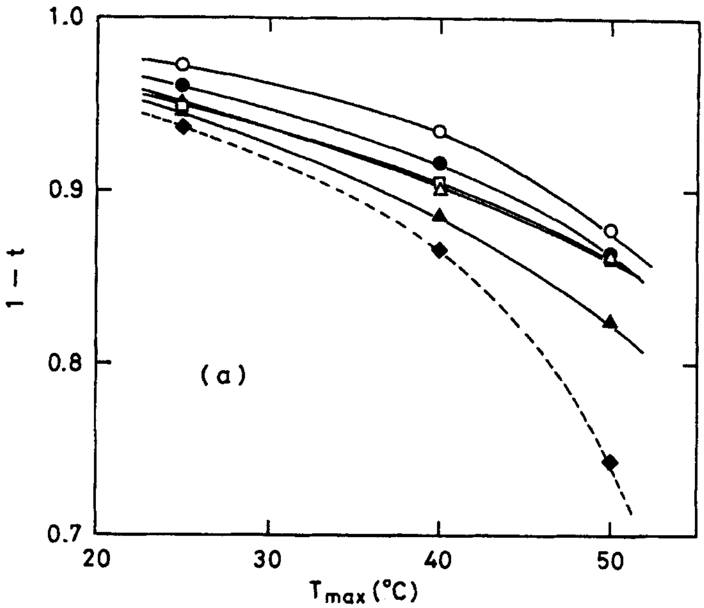
$\Delta\varepsilon^{-1/2}$, because the elastic constants $K(K_{11} + (K_{33} - 2K_{22})/4)$ were almost equal in all the NLC's at 25°C. There was a tendency for $1 - t$ to increase with V_c. However, in the case of PBB $1 - t$ was exceptionally large, in spite of the rather large V_c.

The optical threshold voltage (V_{th}) is almost proportional to V_c. Therefore the temperature dependence of V_{th} is expressed as follows.

$$\frac{1}{V_{th}} \cdot \frac{\partial V_{th}}{\partial T} \propto \frac{1}{K} \cdot \frac{\partial K}{\partial T} - \frac{1}{\Delta\varepsilon} \cdot \frac{\partial \Delta\varepsilon}{\partial T}$$

Table II shows the dielectric constants and K at 0°C and 40°C, as well as their temperature dependence. In the case of PBB, K is small in spite of the rather large $\Delta\varepsilon$, and the temperature dependence of both K and $\Delta\varepsilon$ are large. The large temperature dependence of $\Delta\varepsilon$ compensates that of K, leading to a small t.

Table III shows the multiplexability of an NLC containing 15% of PBB;



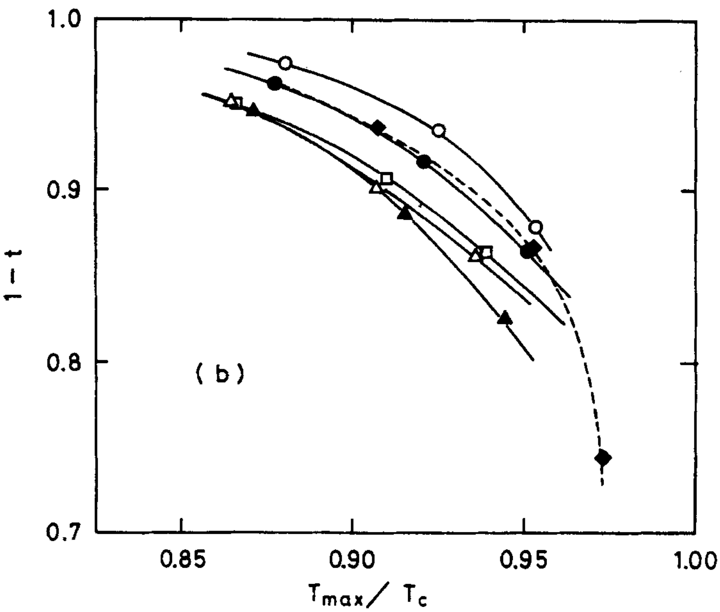


FIGURE 3 T_{max} dependence of $1 - t$. (a) $(1 - t)$ vs T_{max}. (b) $(1 - t)$ vs T_{max}/T_c. ○ PBB, ● PHB, △ T15, □ BCR, ▲ S1225, without N_h.

TABLE II

Dielectric constants, an elastic constant and their temperature dependence for nematic mistures containing N_h. $K = K_{11} + (K_{33} - 2K_{22})/4$.

N_h	Temperature (°C)	ε_{11}	$\varepsilon_{\perp}$	K $\times 10^{-12}$(N)	$\frac{\Delta\varepsilon_0 - \Delta\varepsilon_{40}}{\Delta\varepsilon_0}$	$\frac{K_0 - K_{40}}{K_0}$
PBB	0	13.22	5.77	11.38	0.323	0.389
	40	10.82	5.78	6.95		
PHB	0	12.08	5.88	10.97	0.260	0.356
	40	10.33	5.74	7.07		
T15	0	14.96	5.67	13.43	0.241	0.335
	40	12.68	5.63	8.93		
BCH	0	14.45	5.54	13.09	0.259	0.368
	40	12.24	5.64	8.27		
S1225	0	15.85	5.73	12.38	0.292	0.378
	40	13.03	5.87	7.70		

TABLE III

Multiplexability of a nematic mixture containing PBB. Physical properties of this mixture at 25°C are as follows: $\varepsilon_{\parallel} = 11.78$, $\varepsilon_{\perp} = 5.72$, $K_{33}/K_{11} = 1.08$, $\eta = 40.2$.

Wave-form duty ratio	bias	Temperature range (°C)	V_D (V_{op})	Voltage Martin (M') (%)
1/3	1/3	0–40	3.89	34.7
		0–50	3.80	30.8
1/4	1/3	0–40	4.06	24.9
		0–50	3.97	20.9
1/7	1/4	0–40	4.86	9.5
		0–50	4.76	5.5
1/8	1/4	0–40	5.01	6.8
		0–50	4.91	2.9
1/9	1/4	0–40	5.14	4.7
		0–50	5.04	0.8

1/8 duty driving is possible without temperature compensation by the driving circuitry.

SUMMARY

1. Addition of N_h decreases t.
2. This effect of N_h depends on the dielectric anisotropy, as well as on the increase in T_c.
3. In the case of PBB, the low thresholds voltage was exceptionally compatible with a small temperature dependence of the threshold voltage.

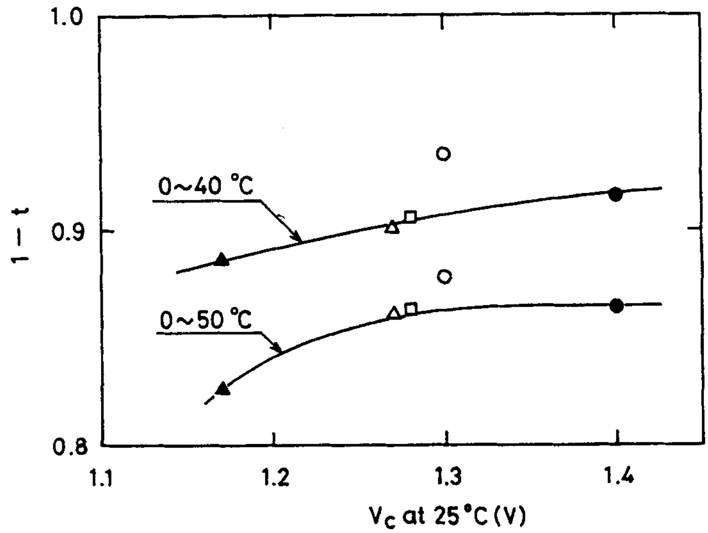


FIGURE 4 Threshold voltage dependence of $1 - t$.

4. The effect of PBB is attributed to a small K and to a large temperature dependence of $\Delta\varepsilon$.

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