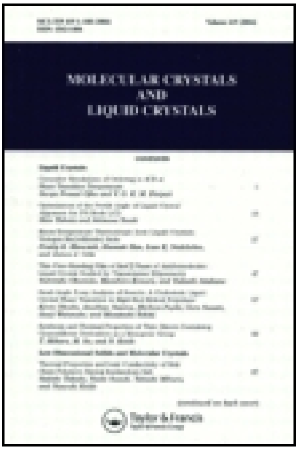

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Improved Temperature Coefficient of Threshold Voltage in Twisted Nematic Liquid Crystals†

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This work is concerned with reducing temperature dependence of the threshold voltage of the TN nematic liquid crystals which consist of majority of *n*-type base mixtures and minority of *p*-type additives.

The temperature coefficient of threshold voltage is closely related to the effective component of permanent dipole moment per molecule of *p*-type additives and becomes smaller with increasing it. The temperature coefficient is independent of the concentration of *p*-type additives.

The mixture, whose temperature coefficient is 0.16%/°C or −3 mV/°C, is developed for seven-to-one multiplexing scheme over the temperature range 0 ~ 40°C without any temperature compensation circuit.

1 INTRODUCTION

The proliferating application of TN LCD's (twisted nematic liquid crystal displays) requires the improvement of multiplexability for LC materials.

As the number of multiplexed lines increases, the electrooptic performance of TN LCD's reduces, that is, the difference between select and nonselect voltage becomes smaller and cross-talk at the nonselect segments becomes visible.

The next three points are practically important for LC materials to keep better multiplexing performance:

(a) steep electrooptic curve,

(b) low temperature dependence of TN threshold voltage,

(c) wide viewing angle.

†Presented at the Eighth International Liquid Crystal Conference, Kyoto, July 1980.

The present work is concerned with reducing temperature dependence of the TN threshold voltage of LC materials for higher multiplexing scheme.

We examined the temperature coefficient of the TN threshold voltage of such systems that consisted of a fixed *n*-type mixture and various kinds of *p*-type additives, and found that the temperature coefficient was closely related to the permanent dipole moment of the *p*-type additives.

2 EXPERIMENTAL

We measured the TN threshold voltage in transmission mode in the region of −5 ~ 50° C to study the effects of the *p*-type additives on the temperature coefficients of the TN threshold voltage of their mixtures.

2.1 Sample preparation

The LC materials we used were the mixtures of esters and PCH's which were given in Table I. They consist of majority of *n*-type (dielectrically negative or near equal to zero) bases and minority of *p*-type (dielectrically positive) additives. The samples No. 1 ~ No. 4 consist of the *n*-type base 1 and various kinds of *p*-type additives. The samples No. 5 ~ No. 7 consist of the *n*-type base 2 and same kinds of *p*-type additives with different concentrations. The *n*-type base 1 and 2 are the mixtures of esters.

The nematic-isotropic transition points of each sample were kept at temperatures above 66°C with minor change of the *n*-type base composition ratio. Crystallization was not observed for any samples which were exposed for a period of 500 hrs. at −25° C.

2.2 TN threshold voltage

The TN threshold voltage is defined as the voltage required for the transmission change by 10%.

The useful parameter describing the cell performance of the TN LCD's is α which shows the ratio of voltages at transmission change of 10% to 70% at 25° C. We used the cells in the measurements whose parameters were $\alpha \leq 1.24$.

The parameter β, which shows the temperature coefficient of TN threshold voltage V_{th}, is defined by[1]

$$\beta = \frac{1}{40}\frac{V_{th}(0) - V_{th}(40)}{\frac{1}{2}[V_{th}(0) + V_{th}(40)]} \times 100\ (\%/°\mathrm{C}), \qquad (1)$$

where $V_{th}(0)$ and $V_{th}(40)$ are the TN threshold voltages at 0° C and 40° C respectively.

TABLE I
Composition of the mixtures in the measurements.

No.	N-TYPE LC	P-TYPE ADDITIVES C_3H_7-◯-COO-◯-CN (MOL %)	C_4H_9-◯-COO-◯-CN (MOL %)	C_3H_7-◯-COO-◯(Cl)-CN (MOL %)	C_3H_7-(H)-◯-CN (MOL %)	C_5H_{11}-(H)-◯-CN (MOL %)	C_7H_{15}-(H)-◯-CN (MOL %)	T_{NI} (°C)	$\Delta\mu^2$ (D^2)
1					13.3	13.3	13.3	70	14.5
2	BASE 1	4			10	10		67	15.5
3		3	12					69	20.7
4		5		8				70	25.4
5	BASE 2	5		8				69	25.4
6		5		9.5				68	25.7
7		5		12				67	26.1

2.3 Calculation of permanent dipole moment of p-type molecules

We calculated the effective component of permanent dipole moment of the p-type molecules $\Delta\mu^2$ by adding up the individual group dipole moments[2] and by averaging in proportion to their molar fractions. $\Delta\mu^2 = \mu_l^2 - \frac{1}{2}\mu_t^2$, where μ_l and μ_t are the average permanent dipole moment of the p-type molecules along the long and short molecular axis respectively. The results are listed in Table I.

3 RESULTS AND DISCUSSION

Figure 1 shows the curve of parameter β vs. $\Delta\mu^2$ for the samples No. 1 ~ No. 4. The parameter β decreases as the effective component of permanent dipole moment of the p-type molecules $\Delta\mu^2$ increases.

We introduce the following two assumptions to discuss these experimental results qualitatively.

(a) The p-type additives dominate the dielectric anisotropy.

(b) The n-type base mixtures dominate the long range order parameter of these systems.

The dielectric anisotropy $\Delta\epsilon$[1,3] of $n + p$ systems is given by

$$\Delta\epsilon = N(A + B/T)S, \tag{2}$$

where A is the constant being proportion to the anisotropy of molecular polarizability of the p-type additives along the long and short molecular axis, B is the constant being proportion to the effective component of permanent dipole moment per molecule of the p-type additives $\Delta\mu^2$, S is the long range order parameter of the n-type base mixture, and N is the number of p-type molecules per unit volume.

The TN threshold voltage V_{th} is given by

$$V_{th} = \pi(K/\Delta\epsilon)^{1/2}, \tag{3}$$

where K is the elastic constant and the relation $K = K'S^2$ (K':constant) holds.

We can obtain an analytical expression by substituting the Eq. (2) into Eq. (3).

$$V_{th}^2 \propto \frac{S}{N(A + B/T)}. \tag{4}$$

Eq. (4) presents a temperature dependence of the TN threshold voltage, that is, $V_{th}^2 \propto ST$ for $A < B/T$ and $V_{th}^2 \propto S$ for $A > B/T$. The temperature coefficient of TN threshold voltage becomes rather small with larger value of the effective component of permanent dipole moment and this is in good agreement with the experimental results in Figure 1.

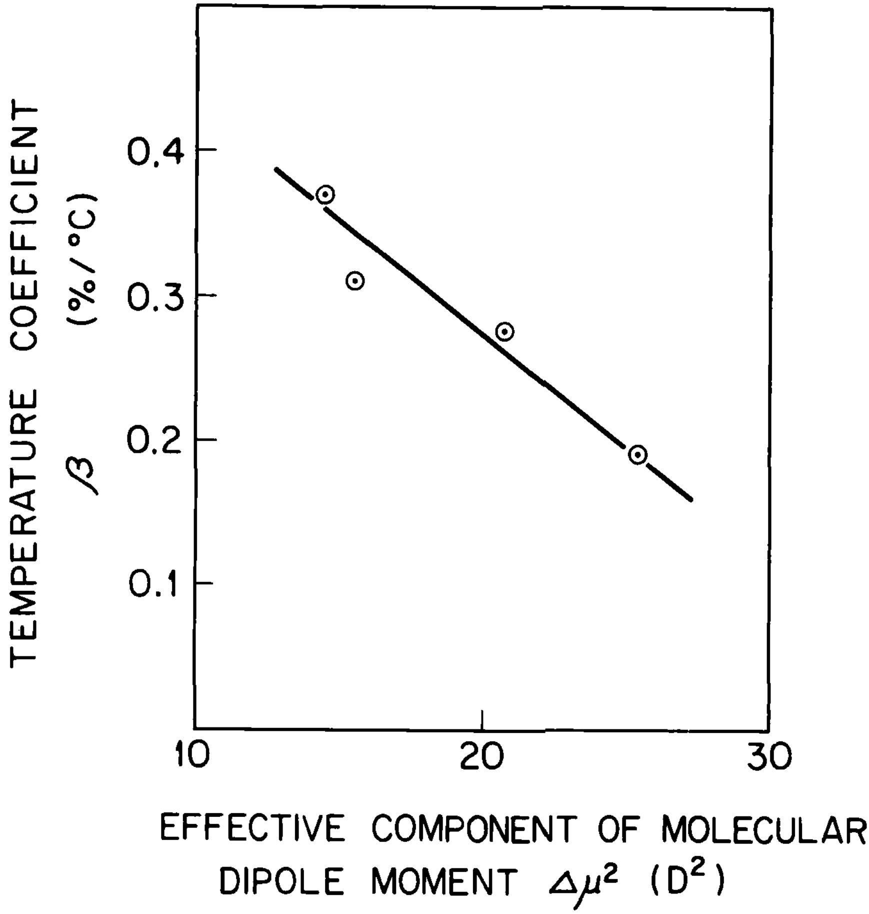

FIGURE 1 β vs. $\Delta\mu^2$ Characteristic.

The parameter β is plotted in Figure 2 for various concentrations of the p-type additive 3′-chloro-4′-cyano-4-n-propylbenzoate (CCPB). The parameter β is kept at nearly constant, $0.16 \sim 0.17\%/°C$, and is little affected by the concentration. We see from Eq. (4) that the temperature dependence of the TN threshold voltage is determined not by N but by $A + B/T$. B is nearly constant within the samples No. 5 ~ No. 7 as shown in Table I. A seems likely to vary little in the concentration range studied. The β value is expected to be independent of it. This agrees well with the experimental results. A small decreasing tendency of β value with increasing concentration of CCPB is due to the fact that CCPB is increased with keeping the amount of another p-type additive 4′-cyano-4-n-propylbenzoate constant, with the result that the effective

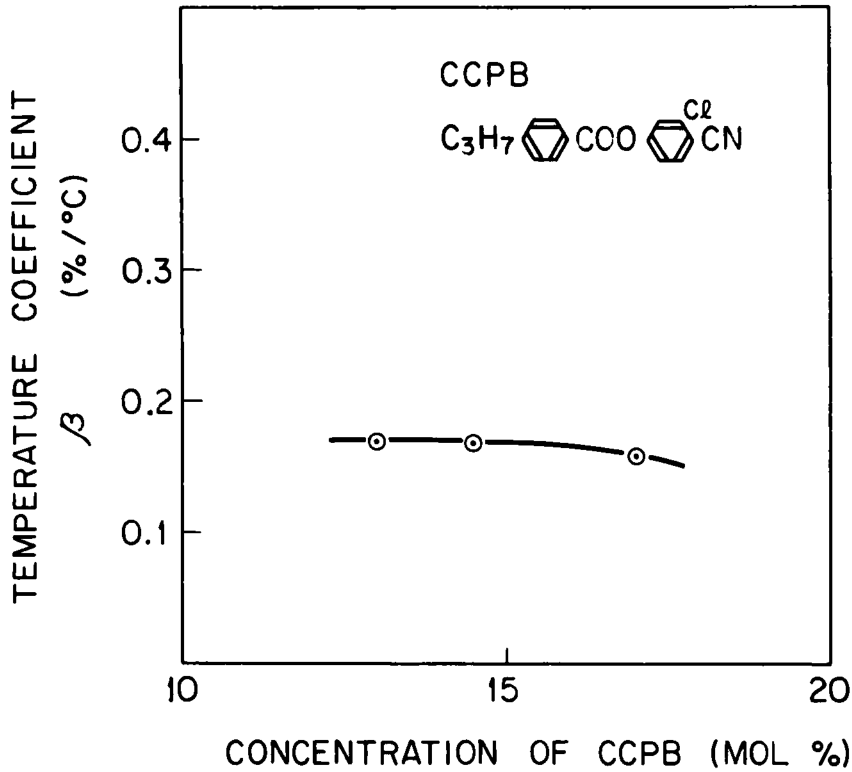

FIGURE 2 β vs. CCPB Concentration.

component of average permanent dipole moment increases a little with an increase in the concentration of CCPB.

In this discussion we consider that the anisotropy of the polarizability A will vary little comparing with the variation of the effective compenent of permanent dipole moment B. But more detailed discussion would be necessary for this point.

4 DOT MATRIX CHARACTER DISPLAY PANEL

We designed a five-by-seven dot matrix character display panel. The LC material we used was No. 7 listed in Table I. It was characterized by a surprisingly small temperature dependence of TN threshold voltage compared to other known nematic materials. The most improved temperature coefficient was 0.16%/°C or −3 mV/°C. The panel was driven using seven-to-one multiplexing scheme over the temperature range 0 ~ 40°C without any temperature compensation circuit. Color display in blue, red, green, etc. is possible using color polarizers because the LC materials are colorless.

5 CONCLUSION

We found that the temperature coefficient of TN threshold voltage of $n + p$ system was closely related to the effective component of permanent dipole moment per molecule of p-type additives $\Delta\mu^2$. Then increasing $\Delta\mu^2$ brought the smaller temperature coefficient of TN threshold voltage. We developed the mixture, whose temperature coefficient was 0.16%/°C or −3 mV/°C, for seven-to-one multiplexing scheme over the temperature range 0 ~ 40°C without any temperature compensation circuit.

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