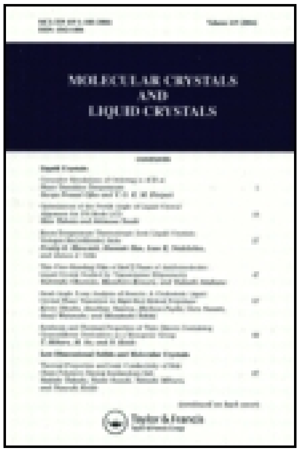

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ON AZIMUTHAL COLOR CONTRAST IN LC DISPLAYS

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Abstract Results of the experimental study of an azimuthal color contrast in the LC displays employing twisted nematic cells with dichroic dyes of different types are discussed.

INTRODUCTION

The use of color rather than monochrome displays for visualizing large amounts of information has been steadily increasing during recent times. Among them the color LC displays (CLCD) are of particular interest since they allow distinguishing different data files by color. Various effects in LCs can be used for CLCDs. LC cells based on the twisted nematics with added dichroic dyes are employed mostly in order to obtain a broad range of chromaticity. Color contrast is one of the most important characteristics in determining the CLCD capabilities. However, lack of knowledge about the color contrast (under diverse observation conditions,in particular) obviously prevents CLCD application in consumer devices, information panels, photocameras, etc.

The present work investigates the azimuthal color contrast in twisted CLCDs with dichroic dyes of different kind.

SUBJECTS OF STUDY

Two types of the CLCDs, employing a combination of the twist- and the "guest-host" effects, have been studied: with the dichroic dyes of different and the same polarity. The CLCD for investigation was designed as two glass plates with the transparent electrodes on the inner surface. An oriented layer of NLC with dyes was filled in a gap of 20μm between the plates. In both types of CLCDs a reflective coating was applied on the external surface of the plate used as the lower one in investigations. A selective polarizer was bonded on another surface of the CLCD with dichroic dyes of

the same polarity.
Four CLCD samples of the first type and three samples of the second type were fabricated for the investigation. All of them had the same nematic matrix based on the mixture of cyanobiphenyls and phenylcyclohexanes doped with the dyes presented in Table 1.

TABLE 1 Dyes composition in CLCD samples

Type of CLCD	Sample No	Content of dye dopes, %
1 - with dichroic dyes of different polarity	1	2,5 KD4 + 0,5 KD184 + 0,9KD8 + 4 KD208
	2	0,625 KD4 + 0,125 KD184 + 0,225 KD8 + + 1 KD208
	3	0,13 KD8 + 0,13 KD6 + 0,04KD2 + + 0,6 KD54 + 0,6 KD92 + 0,6 KD315
	4	1,2 KD4 + 1,9 KD33 + 2 KD36
2 -with dichroic dyes of the same polarity	1	1,5 KD7 + red polaroid film
	2	1,5 KD7 + green polaroid film
	3	1,5 KD7 + neutral polaroid film

All dyes were synthesized in the Research Institute of Extremely Pure Semiproducts and Dyes (NIOPIK) in Moscow by Vladimir G.Rumyantsev who possesses complete information about their chemical composition.
The dyes' optical properties are presented in Table 2.

Table 2. Optical characteristics of dichroic dyes

No	designation	Color	Max. absorbtion wavelength,nm	Dichroism polarity
1	KD4	blue	570/600	negative
2	KD92	blue	570	negative
3	KD54	blue	570	negative
4	KD8	yellow	390	positive
5	KD7	yellow	434	positive
6	KD6	yellow	440	positive
7	KD208	orange	460	negative
8	KD33	red	505	positive
9	KD36	red	505	negative
10	KD261	red	536	negative
11	KD 184	red	520	positive

Application of 4V to the CLCD of the first type resulted in appearance of yellow symbols against the dark-purple background in sample 1 and the lilac background in sample 2 while blue symbols appeared against yellow background in sample 3 and red ones against the blue background in sample 4.

The same action produced the symbols of a color depending on that of the polarizer. Red symbols in sample 1,dark-green symbols in sample 2 and black ones in sample 3 appeared against the goldish-green background.

COLOR CONTRAST MEASURING TECHNIQUES

Chromaticity (x, y) and brightness (Y) were measured by a remote photoelectrical colorimeter whose optical scheme is presented in Figure.1. The device permitted measurements of the transparent and reflective samples.

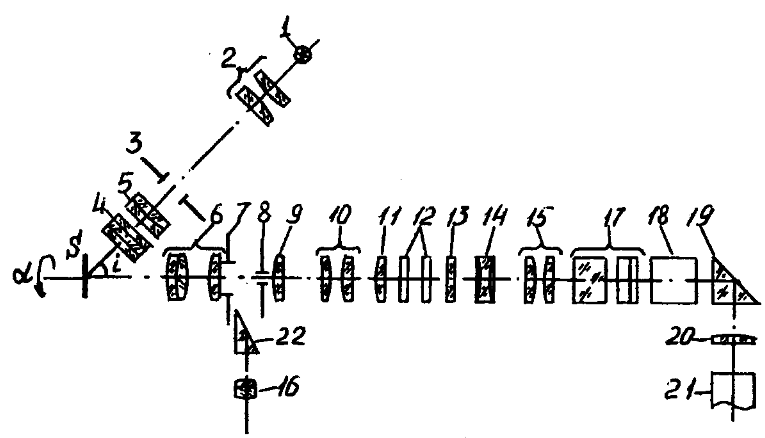

Figure 1. Optical schematic of colorimeter
1 - light source, 2 - condensor, 3 - diaphragm, 4 - filter "C", 5,6 - objectives, 7 - aperture diaphragm, 8 - field diaphragm, 9,10,11,14,15,16,20 - lenses,,12 - attenuator, 13 - correction filter, 17,18,19 - prism attenuator, 21 - photocell, 22 - prism.

i - radiation angle, α - azimuthal angle, S - sample.

The standard colorimetric conditions for the observation angle of 0^o and illumination angle of 45^o were fulfilled. The sample can be azimuthally (angle α) rotated by 15 steps in the plane normal to the colorimeter optical axis.
CIE standard sources A and C were used to provide the uniform illuminance by a parallel beam of measured diameter up to 1 mm . The errors for chromaticity not more than 0,006 and for brightness not more than 5% were ensured.

A CLCD sample's initial position was selected so that the long axes of molecules upon the upper transparent substrate were oriented horizontally at vertical position of the sample.

Both chromaticity and brightness of symbols and backgrounds in the CLCD samples were measured at the azimuthal angles varying from 0^0 to 360^0. Color difference ΔE (l^* u^* v^*) between a symbol and background taken for color contrast measurement and brightness contrast value K were calculated for each angle α by the well-known formula:

$$\Delta E = [(\Delta u^*)^2 + (\Delta v^*)^2 + (\Delta L^*)^2]^{1/2}$$

$$K = \frac{Y_B - Y_S}{Y_B} \quad (\text{if } Y_B > Y_S)$$

$$K = \frac{Y_S - Y_B}{Y_S} \quad (\text{if } Y_S > Y_B)$$

where: $\Delta u^* = u^*_B - u^*_S$; $\Delta v^* = v^*_B - v^*_S$; $\Delta L^* = L^*_B - L^*_S$.
u^*_B , v^*_B - background tristimulus values;
u^*_S , v^*_S - symbol tristimulus values in the system;
L^*_B , L^*_S - background and symbol lightness;
Y_B , Y_S - background and symbol brightness;

Chromaticity diagrams and indicatrices of color and brightness contrast (ΔE and K, respectivly) were plotted by the measurements and calculation results.

RESULTS OF THE CLCD COLOR CHARACTERISTICS STUDY

The results of the experimental study of background and symbol chromaticity are shown in Figure 2 for CLCDs of the first type and in Figure 3 for those of the second type. Examination of the diagrams shows symbol and background chromaticity essentially depending on the type of a dye used. Use of dyes of the same type but of different concentration causes symbols and backgrounds colors to be of little difference (curves 1 and 2 in Figure 2). Use of the same dye and polarizers of different colors in CLCDs of the second type causes close background and quite different symbol colors (Figure 3). Examination of the azimuthal brightness contrast K indicatrix for CLCDs of both types shows that the brightness contrast in all the samples practically does not depend on the azimuthal angle (Figures 4 and 5).

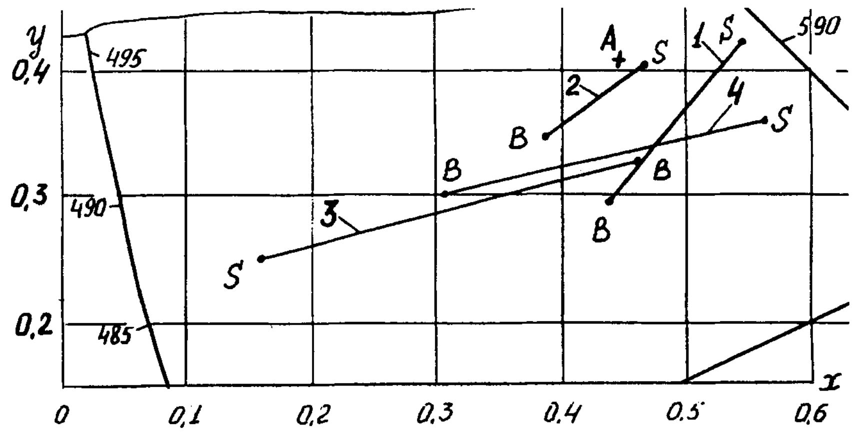

Figure 2. Background (B) and symbol (S) chromaticity for CLCDs with dichroic dyes of different polarity (1st type). Labels 1,2,3,4 refer to the samples' Nos (Table 1)

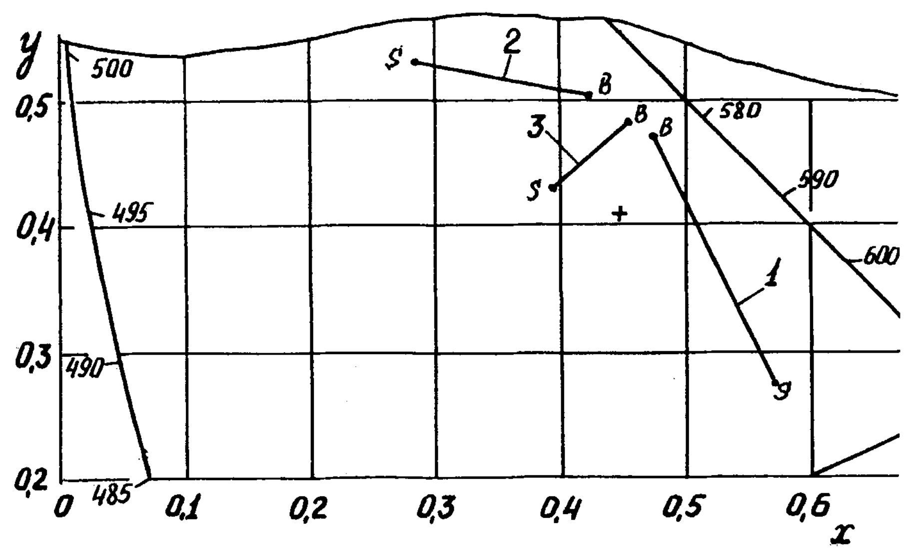

Figure 3. Background (B) and symbol (S) chromaticity for CLCDs with dichroic dyes of same polarity (2nd type). Labels 1,2,3, refer to the samples' Nos (Table 1)

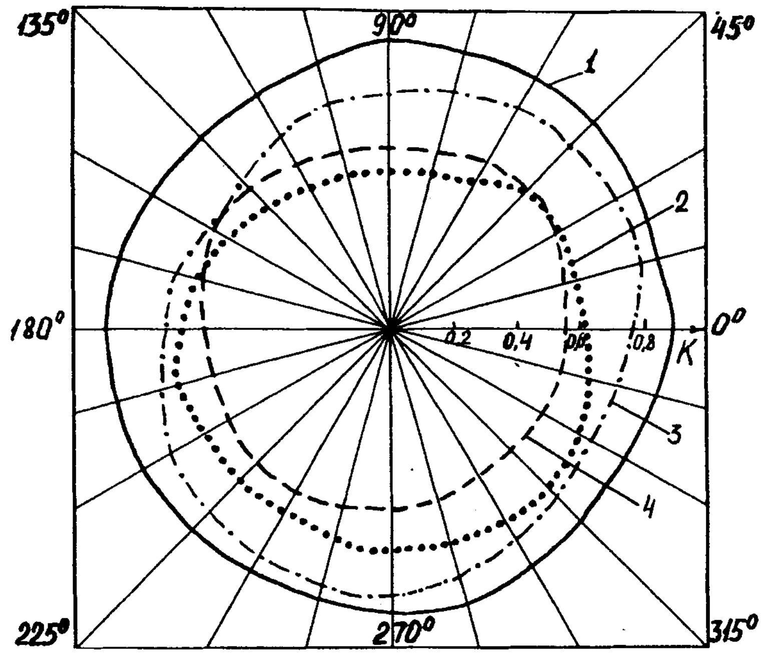

Figure 4. Indicatrices of CLCD azimuthal brightness contrast (1st type). Labels 1,2,3,4 refer to the samples' Nos (Table 1)

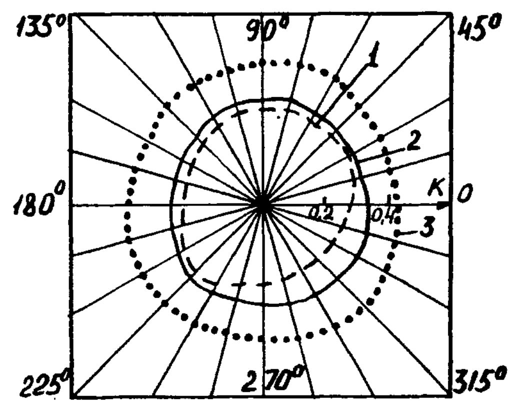

Figure 5. Indicatrices of CLCD azimuthal brightness contrast (2nd type).Labels 1,2,3 refer to the samples' No's (Table 1)

Indicatrices of azimuthal color contrast (ΔE) for the CLCDs of both types shown in Figures 6 and 7 prove that this characteristic essentially depends on angle α . Note that ΔE reaches maximal value when angle α is equal to the

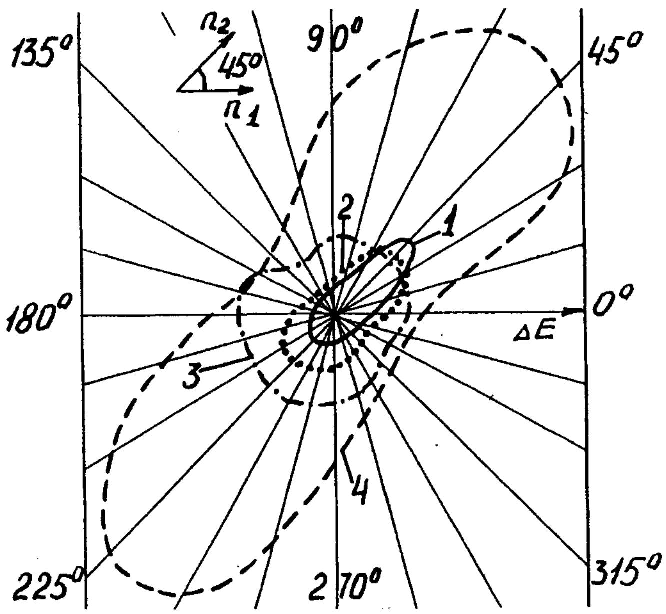

Figure 6. Indicatrices of CLCD azimuthal color contrast (1st type). n_1, n_2– directions of molecules long axes on upper and lower substrates. Labels 1,2,3,4 refer to the samples' Nos (Table 1).

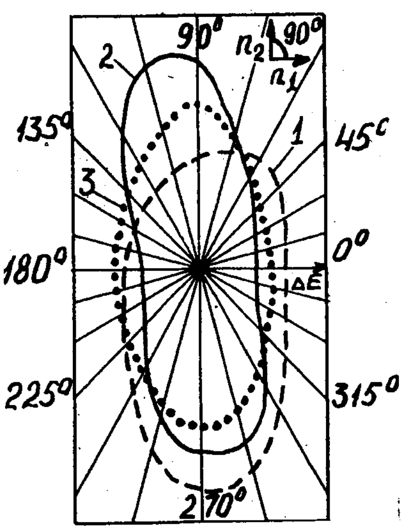

Figure 7. Indicatrices of CLCD azimuthal color contrast (2nd type). n_1, n_2– directions of molecules long axes on upper and lower substrates. Labels 1,2,3 refer to the samples' Nos (Table 1).

twisting angle of long axis of a molecule placed between the upper and lower substrate, e.g. 45 for CLCDs of the first type and 90 for those of the second type.
Sample 4 shows the maximal contrast (ΔE_{max} =108) among CLCDs of the first type, having max/min contrast ratio $\Delta E_{max}/\Delta E_{min}$ = 5 : 1. Among CLCDs of the second type sample 1 shows the maximal contrast (ΔE_{max} = 70), having the same ratio $\Delta E_{max}/\Delta E_{min}$ = 3 : 1.

SUMMARY

This study reveals significant anisotropy of the azimuthal color contrast in twisted CLCDs with dichroic dyes. In order to obtain the maximal color contrast, a CLCD has to be positioned with respect to the observer so that the long axes of molecules on the lower plate are oriented horizontally. Among the samples studied, sample 4 of CLCD of the first type features maximal color contrast.

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