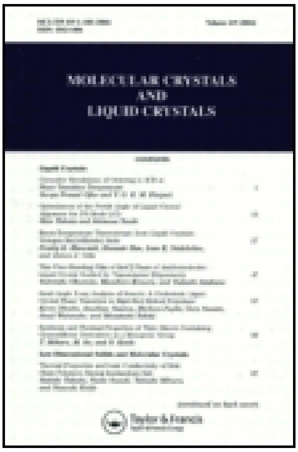

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Electrooptic Properties of “Superplanar” LC Layer

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Electrooptic Properties of "Superplanar" LC Layer

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Electric controlled birefringence in a homogeneous nematic LC layer with additional compensating optic elements (uniaxial birefringent plate and another LC layer) which allowed the removal of colour and angular dependence of transmission has been investigated.

Keywords: superplanar, birefringence, compensation

INTRODUCTION

It is known that application of a Nematic Liquid Crystal (NLC) layer as an electrically controlled display becomes possible due to existence, on the layer's Transmission-Voltage Curve (TVC), of parts of variable (on the order of one or two) light transmission as a function of applied voltage. By creating various conditions for NLC director orientation on the surfaces restricting the said layer, by varying the LC material composition, as well as by varying arrangement of polarizers relative to each other and to the director, it is possible to obtain displays drastically differing in their electrooptic characteristics.

This paper deals with investigation of electro-optic properties of homogeneous NLC layers with positive dielectric anisotropy (Electric Controlled Birefringence, ECB) together with some additional optic elements enabling significant improvement of angular and spectral characteristics of common electro-optic ECB layers. Comparison between electro-optic parameters for such display (steepness of TVC and switching times) and those for similar twisted nematic layers (values of layer thickness and temperature are in both cases the same) is also given.

RESULTS AND DISCUSSION

The curves shown in Figure 1 represent typical electro-optic characteristics of twisted nematic and ECB layers. The TVC slope for the twist effect is characterized by steepness parameter defined as

$$p = \frac{U_{sat} - U_{th}}{U_{th}},$$

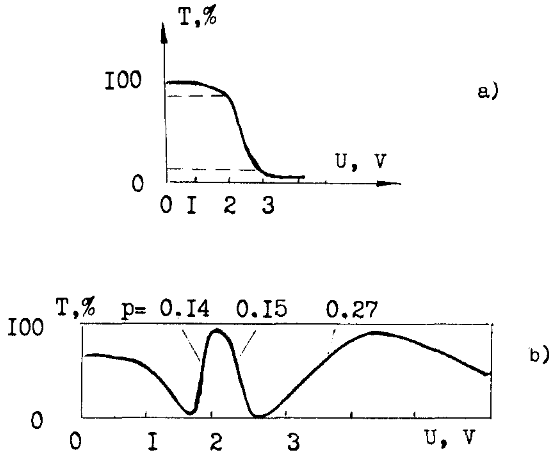

FIGURE 1 Transmission voltage curves for twist (a) and CBE effects (b). The LC layer thickness for both cases is 11 μm. The LC material is the same.

where U_{th} is threshold voltage (for crossed polaroids it corresponds to 90% transmission), U_{sat} is saturation voltage (10% transmission). This parameter is known to play an important role in operation of matrix Liquid Crystal Displays (LCD) based on multiplex drive. Another important factor to be considered in designing such LCDs is fast response of their electro-optic elements.

Similar parameters can be considered in discussing LCD based on the ECB effect. Here, however, the peculiar feature of the TVC is its oscillating character when the slopes of different signs alternate, the steepness and response of these TVC parts differ drastically from each other.

Steepness and switching times for electro-optic elements based on the ECB effect are given in Table I. For comparison, experimental data for a twisted nematic electro-optic element is given for the same NLC material (d = 11 μm). From Table I it can be seen that growth of number, m, of the ECB TVC part (in other words, decrease in the driving voltage applied to the LCD) leads to a drop in steepness parameter, p, and to a sharp increase in time spent for element switching from transparent state to non-transparent and vice versa. Such behaviour makes it impossible to use the TVC parts with large m for fast response multiplex drive displays. In both cases the part with number $m = 1$ possesses the fastest response. However, for $m = 1$, of the two LC layer thicknesses—25 and 11 μm—the latter would be preferable due to low operating voltages and lower steepness parameter for almost the same response values. Comparison of results given in Tables I and II leads to the conclusion that in terms of steepness and response the ECB LCD is more advantageous than the TN LCD.

It should be noted however that a conventional electro-optic ECB LCD has a number of drawbacks. Firstly, for large enough (more than π) phase differences between ordinary and extraordinary waves in the LC layer, the LCD appears to be coloured. Secondly, there is a noticeable angular dependence of its optic trans-

TABLE I

Switching times T_{on} and T_{off}, steepness parameter p and allowable number of lines on a display N versus number of ECB TVC's part m

LC layer thickness, μm	m	U_{max}, V	U_{min}, V	T_{on}, ms	T_{off}, ms	p	N
25	1	7.1	4.037	15	56	0.411	9
	2	3.037	4.037	127	64	0.2	30
	3	3.037	2.57	118	191	0.107	97
	4	2.26	2.57	253	208	0.08	208
	5	2.26	2.037	270	372	0.064	260
	6	1.85	2.037	462	410	0.062	277
	7	1.85	1.687	543	715	0.056	337
11.8	1	4.023	2.46	19	54	0.268	18
	2	1.975	2.46	80	69	0.154	49
	3	1.975	1.607	180	169	0.14	58

TABLE II

Switching times T_{on} and T_{off}, steepness parameter p and allowable number of lines on a display N for twist effect (LC layer thickness 11.8 μm)

U_{max}, V	U_{min}, V	T_{on}, ms	T_{off}, ms	p	N
0	4.162	60	85	0.37	10

mission in the plane passing through the light wave propagation direction and the LC director.

This paper reports remedies to avoid the above drawbacks. In order to remove the LCD's colour, a compensating uniaxial birefringent plate is placed between the LC layer and one of the polarizers (see Figure 2). The optical axis of the plate is normal to the director in the LC layer while the thickness and optical anisotropy are chosen such that for wavelengths in the middle of the visible spectrum range, the phase difference between ordinary and extraordinary waves coincides in its absolute value with the phase difference of these waves in the LC layer for the selected operating voltage range. As a result, the obtained phase difference in the LC layer will be compensated by the given optically anisotropic plate. The resultant

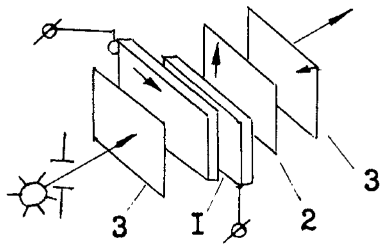

FIGURE 2 Diagram of a "superplanar" LC layer: 1) homogeneous LC layer; 2) compensating birefringent plate; 3) polarizers.

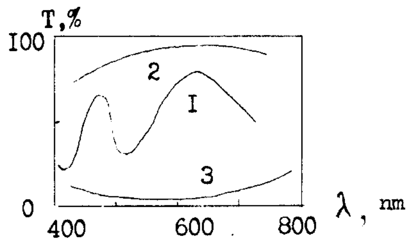

FIGURE 3 Transmission spectra for the LC layer: 1) without compensating plate; 2) and 3) with compensating plate.

phase difference at the LCD output, almost in the whole visible wavelength range for operating voltages, will approach zero and the colour will practically disappear.

This condition agrees quite well with the experimental data. Figure 3 shows three optic spectra for the ECB LCD. Curve 1 represents a case without a compensating plate, with voltage applied to the electrodes 4 V and phase difference 4π. The spectrum has a pronounced nonuniform character testifying of coloured transmission. Curves 2 and 3 represent cases with a compensating plate for phase difference 4π. Spectrum 2 is taken for 4.9 volts while Spectrum 3 is for 4 volts. It can be seen that use of the compensating birefringent plate converts the strongly nonuniform Spectrum 1 into almost uniform 2 and 3.

A compensation method, similar to some extent, is applied for improvement of the ECB effect using an NLC layer with original homeotropic director alignment.[1,2]

The angular dependence of optical transmission for the discussed ECB LCD was successfully removed by using two LC layers, when one homogeneous LC layer was followed by a similar layer of the same liquid crystal. These layers however had opposite director tilt directions preset by the direction of rubbing of the orienting agent on the corresponding electrodes. Schematic design of such device is shown in Figure 4a. Both LC layers in question were placed between crossed polarizers and had phase difference about 4π. Voltage U_1 controlling the transmission was applied to the first layer while U_2 (of constant amplitude) was applied to the second layer enabling the selected director tilt in the second layer. The value of the director tilt angle in the second layer was chosen close to that of the first layer within the operating voltage range U_1 of the display. As a result, the angular transmission dependence vanished which is confirmed by the experimental data

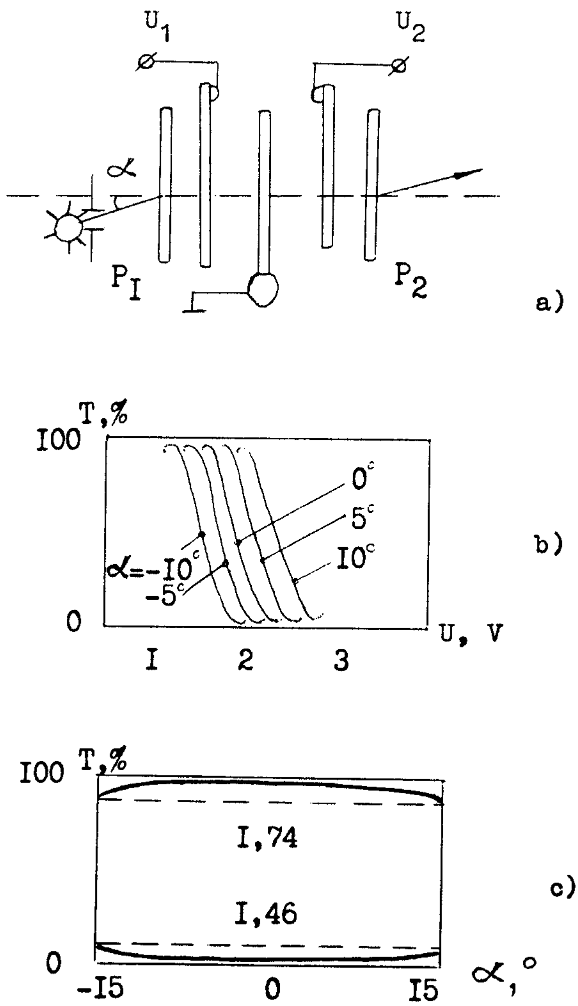

FIGURE 4 a) Diagram of a two-layer system with opposite director tilts; b) TVCs of an LC layer for various angles of incidence of He-Ne laser beam; c) Transmission of a two-layer system versus beam incidence angle for various voltages.

given in Figures 4b and 4c. Figure 4b shows TVCs for various angles in one LC layer. Figure 4c illustrates two LCD angular transmission dependencees T(α) for two U_1 voltages: 1.74 V (T > 0.9) and 1.46 V (T < 0.1). The magnitude of U_2 applied to the second LC layer was chosen to be 1.46 V.

CONCLUSION

It follows from the above that we investigated an electro-optic ECB LCD with a homogeneous LC layer which we called a "superplanar" layer. It differed from the conventional ECB LCD designs by special compensating optic elements (a uniaxial birefringent plate and another LC layer possessing properties similar to the first layer) which allowed the removal of colour and angular dependence of transmission. Such devices can be successfully used in fast response achromatic matrix multiplex LCDs.

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