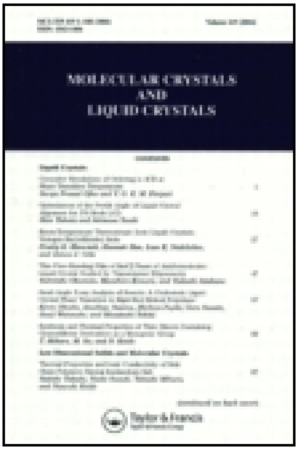

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 04 Oct 2006

Mol. Cryst. Liq. Cryst., 1999, Vol. 331, pp. 201-208
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Influence of Transverse Dipole Statistics on Transmission Characteristics of Antiferroelectric Liquid Crystal Displays

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It has been suggested by A. Fukuda et al. that the pairing of transverse dipole moments is responsible for the antiferroelectric interaction between adjacent layers in an antiferroelectric liquid crystal. In a previous article we showed that a negative surface interaction coefficient, probably also caused by the pairing of transverse dipole moments, can explain the thresholdless characteristic of an antiferroelectric liquid crystal. In the present paper we investigate if the influence of population statistics of the transverse dipole moments, can have some effect. It is found that they cause an effective negative surface interaction coefficient, but only at sufficiently large electric fields. At smaller electric fields the transmission characteristic has a threshold field. We conclude that the bulk behaviour of transverse dipole moments cannot explain the thresholdless transmission characteristic.

Keywords: antiferroelectric; dipole statistics; transmission

INTRODUCTION

Recently the thresholdless antiferroelectric liquid crystal (TLAFLC) was discovered[1,2,3] and excellent prototype displays have been demonstrated[3,4]. A group around Fukuda[1,2] suggested that the typical thresholdless transmission-voltage characteristic of Figure 1 can be explained by the pairing of transverse dipole moments. Our group[5] showed that a negative surface-interaction coefficient, probably caused by the polar interaction of the paired transverse dipole moments with the alignment layers, explains in a simple way the thresholdless transmission-voltage characteristic.

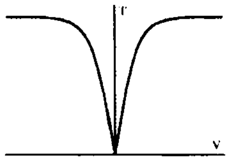

FIGURE 1 Transmission-voltage characteristic of TLAFLCD

In the present paper we want to investigate if the bulk properties of the transverse dipole moments could also be responsible for the thresholdless transmission-voltage characteristics. In Figure 2 a single layer of a smectic C* liquid crystal is presented. The macroscopic polarisation density $\overline{P}$ within one layer is situated in the layer plane and perpendicular to the director. The transverse dipole moments, introduced by Fukuda, are dipole moments of

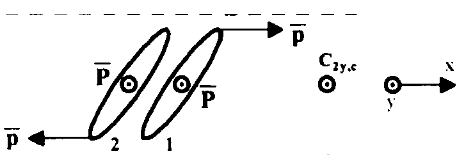

FIGURE 2 One layer of smectic C* type LC

individual molecules, that are perpendicular to the macroscopic polarisation and are also situated in the layer plane. It was called "transverse" by Fukuda, because it is perpendicular to the macroscopic polarisation. Also according to Fukuda, they are situated near the layer interfaces. Because of the two-fold symmetry axis in the centre of the layer, $C_{2y,c}$, there must be as many molecules with the transverse dipole moment at the top boundary (type 1 in

Figure 2) as at the lower boundary (type 2 in Figure 2). These transverse dipole moments have no influence on the director motion, since director motion describes the motion of the average molecule and the average transverse dipole moment is zero. If however an electric field is applied parallel to the boundary layers and making an angle φ with the y-axis, the molecules of type 1 are energetically favoured. If the electric field varies sufficiently slowly, so that thermal equilibrium statistics are valid (a typical relaxation time is 10^{-6} sec), the average polarisation density component along the electric field caused by the transverse dipoles, becomes

$$Np\sin\varphi\,\frac{e^{\frac{pE}{kT}\sin\varphi}-e^{-\frac{pE}{kT}\sin\varphi}}{e^{\frac{pE}{kT}\sin\varphi}+e^{-\frac{pE}{kT}\sin\varphi}}=Np\sin\varphi\,th\left(\frac{pE}{kT}\sin\varphi\right) \tag{1}$$

where N is the density of pairs of molecules.

Model for the AFLC

We follow the model for AFLC developed in earlier papers[6,7,8]. It assumes that the smectic layers have the bookshelf structure and that the director

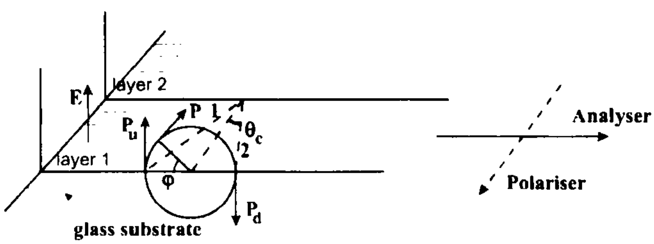

FIGURE 3 Director position on the cone. Up and down state.

orientation within a layer is homogeneous. The position of the director on the cone is described by the azimuthal angle φ as shown in Figure 3. The antiferroelectric character of the liquid crystal results in the fact that the directors in adjacent layers tend to be at opposite sides of the cone. We shall therefore refer the azimuthal angle φ_1 in the first layer with respect to the "polarisation up" state and the angle φ_2 in the adjacent layer with respect to the "polarisation down" state. Without taking the transverse dipole moments into account, the energy density of a (φ_1, φ_2) state can be expressed as

$$W = -A\cos(\varphi_1 - \varphi_2) - EP\cos\varphi_1 + EP\cos\varphi_2 - \gamma\left(\cos^2\varphi_1 + \cos^2\varphi_2\right) \quad (2)$$

The first term expresses the "antiferroelectric" tendency of the directors in adjacent layers to be at opposite sides of the cone. The next two terms express the tendency of the polarisations in adjacent layers to align with the electric field. The last term expresses the interaction with the alignment layers. In a normal antiferroelectric liquid crystal, the coefficient γ is positive. This term is then minimal if $\varphi_1 = \varphi_2 = 0$ i.e., if the molecules are parallel to the glass surfaces.

In the present paper we shall also assume that γ is positive, but we shall add the influence of the transverse dipole moments. In Equation (2) for the energy density, two terms should be added :

$$-NpE\sin\varphi_1\, th\left(\frac{pE}{kT}\sin\varphi_1\right) - NpE\sin\varphi_2\, th\left(\frac{pE}{kT}\sin\varphi_2\right)$$

In all the examples we will calculate later on, it turned out that $pE/kT < 1/4$, so that we may approximate $th\, x$ by x, and obtain

$$W = -A\cos(\varphi_1 - \varphi_2) - EP\cos\varphi_1 + EP\cos\varphi_2 - \gamma\left(\cos^2\varphi_1 + \cos^2\varphi_2\right) - \frac{Np^2E^2}{kT}\left(\sin^2\varphi_1 + \sin^2\varphi_2\right)$$

Since $sin^2\varphi = 1 - cos^2\varphi$ the energy density can be written as

$$W = -A\cos(\varphi_1 - \varphi_2) - EP\cos\varphi_1 + EP\cos\varphi_2 - \gamma'(\cos^2\varphi_1 + \cos^2\varphi_2) \quad (3a)$$

with

$$\gamma' = \gamma - \frac{Np^2E^2}{kT} = \gamma - aE^2 \quad (3b)$$

Originally we thought that this expression could be used to explain the existence of a negative γ', but because γ' only becomes negative for sufficiently large E, it turns out that the behaviour is different from the situation of a negative γ as explained in [5].

In order to explain this behaviour, we shall first explain the characteristic in the case of a positive γ without transverse dipoles. This is shown in Figure 4 and explained in [6,7,8]. Starting from $E=0$ and increasing E, the liquid crystal remains in the antiferroelectric state with $\varphi_1 = \varphi_2 = 0$, i.e. the directors parallel

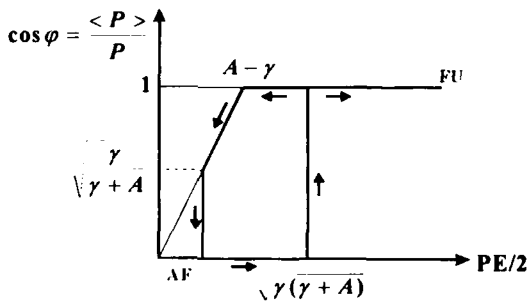

FIGURE 4 Average <P> versus E for an ordinary AFLC

to the glass at opposite sides of the cone. At a threshold value the liquid crystal jumps to the ferroelectric up state with $\varphi_1 = 0$ and $\varphi_2 = \pi$, i.e. the directors parallel to the glass but now at the same side of the cone. With decreasing E, the liquid crystal remains in that state until at $PE=2(A-\gamma)$, it goes to the "symmetrical up" state with $\varphi_1 = \varphi$, $\varphi_2 = \pi-\varphi$ and $cos\varphi$ proportional to E. In this situation the directors in adjacent layers start from parallel to the glass at the same side of the cone (position 1 in Figure 3), start tilting with respect to the glass at the upper and lower part of the cone, until they reach a maximum tilt described by $cos\varphi$ $/\gamma(\gamma+A)/^{1/2}$. If E decreases even further the liquid crystal jumps back to the AF state from which it started. In [6,7,8] it is explained that the light transmission follows approximately the same pattern as $cos\varphi$.

If we now take the influence of the transverse dipoles into account we obtain the characteristic shown in Figure 5. For small E we start from the AF state with the directors parallel to the glass surface. At $E_0=(\gamma/a)^{1/2}$, γ' becomes zero, and in the interval $(0,E_0)$ γ' goes from γ to 0. Somewhere in between γ becomes so small that the threshold value for the AF state will be reached, i.e.

$$\frac{PE}{2}=\sqrt{\gamma'(\gamma'+A)}$$

from which one easily calculates

$$e_t^2=\frac{1}{2\alpha\gamma}+\frac{A}{2\gamma}+1-\sqrt{\left(\frac{1}{2\alpha\gamma}+\frac{A}{2\gamma}\right)^2+\frac{1}{\alpha\gamma}} \tag{4}$$

$$\text{with } e=\frac{PE}{2}\sqrt{\frac{\alpha}{\gamma}} \text{ and } \alpha=\frac{4a}{P^2} \tag{5}$$

For larger E the liquid crystal jumps, not to the FU state, but to the SU state with $\varphi_1=\varphi$ and φ_2 π-φ (provided A $>3\gamma'$) with

$$\cos\varphi=\frac{PE}{2(A-\gamma')}=\frac{e}{\sqrt{\alpha\gamma}}\cdot\frac{1}{\frac{A}{\gamma}-1+e^2} \tag{6}$$

This curve has a parabolic shape. For sufficiently large E the FU state is finally reached. With decreasing E we first stay in the FU state, then go to the SU state with ever increasing angle φ (and corresponding tilt with respect to the glass surfaces), but since again we reach positive values of γ', the minimum value of $\cos\varphi$ (i.e. maximum value of φ and maximum tilt)

$$\cos\varphi = \sqrt{\frac{\gamma'}{\gamma' + A}} \tag{7}$$

is reached where the liquid crystal jumps back to the AF state.

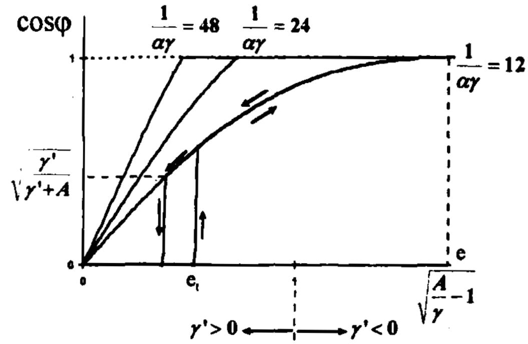

FIGURE 5 <P> versus E characteristic for A/γ=4

In Figure 5, this characteristic is shown for $A/\gamma=4$ and various values of $\alpha\gamma$, i.e., $1/12$, $1/24$ and $1/48$. At the top of the curve with $\cos\varphi_m=1$, one has $pE/kT=1/4$ if $P=Np$. Only for $1/\alpha\gamma=12$, the complete characteristic is shown. For $1/\alpha\gamma=12$, 24 *and* 48 the corresponding values of e_t are 0.53, 0.412 *and* 0.305. In Figure 6, we have presented the case $A/\gamma=10$. Here the various values for $1/\alpha\gamma$ are 36, 72 *and* 144 and the corresponding values of e_t are 0.48, 0.36 *and* 0.266. Both figures show, that γ' becomes negative only for sufficiently large electric fields. This causes that for lower electric fields a threshold and hysteresis remains, so that the population statistics of transverse electric dipoles cannot explain the typical thresholdless characteristic.

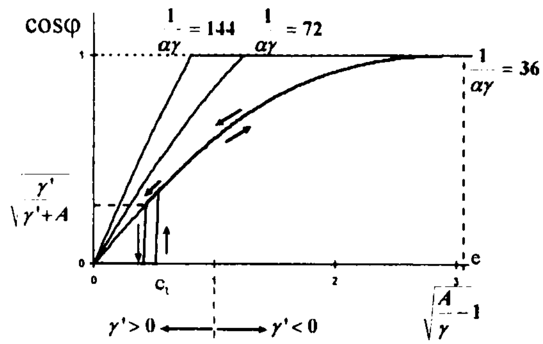

FIGURE 6 <P> versus E characteristic for A/γ=10

Acknowledgement

The authors thank Prof. A. Fukuda for discussing his model of transverse electric dipoles with them.

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