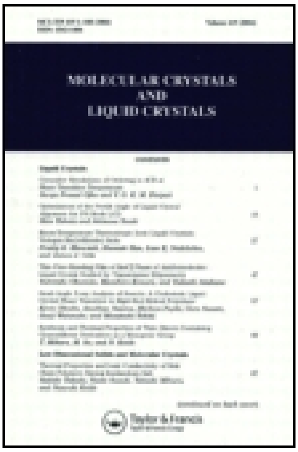

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Structure and Properties of the Inversion Line in the Chevron Sample of the Ferroelectric Liquid Crystal

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Structure and Properties of the Inversion Line in the Chevron Sample of the Ferroelectric Liquid Crystal

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In chevron samples of ferroelectric liquid crystals (FLC) the twisted molecular organization is confined either to the upper part of chevron with lower part untwisted or *vice versa.* Therefore two different director configurations with respect to the chevron interface can coexist and they can be mediated by so called inversion line. The structure of the inversion line is proposed using the simpliest approximation of FLC elasticity and its basic properties like their creation and ineraction with unwinding lines is discussed.

Keywords: ferroelectric liquid crystals, chevron, inversion line

INTRODUCTION

The molecular twisted structure in one part of chevron either above or below the chevron interface in thin ferroelectric liquid crystals (FLC) samples without an electric field was reported in the Ref.[1,2]. The optical properties of FLC sample with such a different molecular organization on the opposite sides of the chevron interface, i.e. with the twisted structure on one side of chevron followed by the uniform structure on the other side were studied in the Ref.[3]. The existence of the different molecular orientation with respect to the chevron interface leads to the occurence of two different states with either the twist in the upper part of chevron and the uniform arrangement of molecules in its lower part or the uniform molecular organization in the upper and the twist in the lower part of chevron, respectivelly. Therefore there could be a line separating these two different states of molecular organization. Such a line, called the inversion line, was really observed[2,3] (see also the photos in Ref.[1,4]). The difference in the light propagation on both sides of the inversion line leads to the differently coloured sample parts (called chevron surface domains[1,9]) separated by this inversion line.

THE STRUCTURE OF THE INVERSION LINE

In order to obtain a simplified description of the inversion line structure we will use the approximate model of chevron as follows:

(i) The smectic C* layers in the sample of the finite thickness D are inclined from the upper and lower surface by the angle δ and $-\delta$, respectively. If the chevron interface is situated at $x = D_0 \neq D/2$ (the x-axis is perpendicular to the sample surfaces) the smectic C* layers are displaced (relatively to the reference state without chevron where the smectic layers are perpendicular to the sample surfaces) by the displacements u^+ and u^- in the upper and lower part of chevron. The displacements u^+ and u^- are oriented in the z - axis direction (i.e. in the direction normal to smectic layers) and they can be expressed as $u^+(x)=(D-x)\tan\delta$ for $D_0<x<D$ and $u^-(x)=(x+D-2D_0)\tan\delta$ for $0<x<D_0$. Both the molecular tilt angle θ and the layer thickness will be constant in the upper and lower part of chevron. The molecular orientation in layers will be characterized by the **t** - vector which is the orientation of the molecular projection into the smectic layers. If the **t**-vector makes an angle Φ with the y-axis it can be expressed as $\mathbf{t}=(-\sin\Phi, \cos\Phi)$. To simplify the problem the **t** - vector orientation can be studied in the reference state and finally transformed from the reference state by the displacements u^+ and u^- to the chevron layer structure. This simplification is therefore valid for small layer tilt angle δ.

(ii) The chevron interface situated at $x = D_0$ will be taken as a barrier which separate the upper and lower part of chevron preventing the propagation of the twist deformation from one part of the sample to the other part. The theoretical model of the chevron with this property was recently proposed[5].

Under the assumptions (i) and (ii) we will treat the upper and lower part of chevron independently. The bulk elastic free energy ρf can be then expressed in both parts of chevron in the form given in [6] for the elastic constants $B_1 = B_2$ and which depends only on derivatives of Φ and not on layer deformations:

$$\rho f = \frac{B_1}{2}\left(\frac{\partial\Phi}{\partial x}\right)^2 + \frac{B_3}{2}\left(\frac{\partial\Phi}{\partial z} - q\right)^2, \tag{1}$$

where B_1 and B_3 are the smectic C* elastic constants and $q = 2\pi/Z$, where Z is the helicoidal pitch.

The equilibrium equation describing the **t** - vector orientations in the upper and lower part of the chevron and which follows from (1) can be written as:

$$B_1\frac{\partial^2\Phi}{\partial x^2} + B_3\frac{\partial^2\Phi}{\partial z^2} = 0, \tag{2}$$

for both $\Phi = \Phi^+$ (the solution in the upper part of the chevron) and $\Phi = \Phi^-$ (for the lower part).

Let the line singularity connecting the twisted and homogeneous director orientations in the upper part of chevron is situated at the point $x = D_0$, $z = 0$ and it is parallel to y-axis. Then the solution $\Phi^+(x,z)$ in the upper part of chevron can be proposed in the form:

$$\Phi^+(x,z) = \frac{\Delta\Phi^+}{\pi}\arctan\left[\tanh\left(\frac{\pi z}{2\alpha(D-D_0)}\right)\cot\left(\frac{\pi(x-D_0)}{2(D-D_0)}\right)\right] + \frac{\Delta\Phi^+}{2}\,\frac{x-D}{D-D_0} + \Phi_b^+. \tag{3a}$$

Analogously the solution at the lower part of chevron and situated at $x = D_0$, $z = 0$ can be written in the form:

$$\Phi^-(x,z) = \frac{\Delta\Phi^-}{\pi}\arctan\left[\tanh\left(\frac{\pi z}{2\alpha D_0}\right)\tan\left(\frac{\pi x}{2D_0}\right)\right] + \frac{\Delta\Phi^-}{2}\,\frac{x}{D_0} + \Phi_b^-, \tag{3b}$$

where $\alpha = (B_3/B_1)^{1/2}$, $\Delta\Phi^+ = \Phi_b^+ - \Phi_c^+$, $\Delta\Phi^- = \Phi_c^- - \Phi_b^-$. The parameters Φ_b^+ and Φ_b^- are the **t**-vector orientations on the upper and lower sample surface which we take in the form $\Phi_b^+ = \Phi_o$, $\Phi_b^- = \pi+\Phi_o$. The parameters Φ_c^+ and Φ_c^- are the **t**-vector orientations on the upper and lower chevron interface and their equilibrium values follow from the continuity of the director at the chevron interface as discussed e.g. in the Ref.[1]. The equilibrium values of the parameter Φ_c^+ are $\pi - \Phi_o$ ($z<0$) and Φ_o ($z>0$). As for the parameter Φ_c^- its equilibrium values are either $\pi+\Phi_o$ ($z<0$), or $-\Phi_o$ or $2\pi-\Phi_o$ for $z>0$. The angle Φ_o corresponding to the planar orientation of the surface molecules in inclined layers it is connected with δ and θ as[1] $\sin\Phi_o = \tan\delta/\tan\theta$. The detailed discussion of solutions describing the inversion lines will be given in the Ref.[7].

The director distributions describing two possible inversion lines are presented (Fig.1). In Fig.1a,b the so called asymmetric and symmetric inversion lines are shown. Both lines have the same equilibrium values of the parameter Φ_c^+. In the case of asymmetric inversion line the equilibrium values of Φ_c^- are $\Phi_c^- = \pi+\Phi_o$ ($z<0$) and $\Phi_c^- = -\Phi_o$ ($z>0$) and therefore the molecules rotate in the same sense. The molecules in the lower part of chevron should make a greater rotation (Fig.1a) as compared with the molecules in the upper part. In the case of the symmetric inversion line ($\Phi_C^- = \pi+\Phi_O$ (z<0) and $\Phi_C^- = 2\pi-\Phi_O$ (z>0)) the molecules rotate in the opposite sense (Fig.1b) but for the same angle.

DISCUSSION

In thin samples of the thickness smaller than 2μm when the zig-zag defect is present there could be a difference in the positions of chevron interfaces on both sides of the zig-zag[9] so chevron interfaces are not situated in the sample centre. The twisted structure generally occurs in the thicker part of the sample between a sample surface and chevron interface what corresponds to the lower twist deformation energy. If e.g. on one side of zig-zag the thicker part is situated between the upper sample surface and chevron interface, on the other side of zig-zag the thicker part of the sample is then between the chevron interface and the lower sample surface. With the twist in thicker parts of the sample and the uniform structure in thinner parts we are therefore in the situation when the zig-zag defect coincides with the inversion line. Such a situation was also confirmed by our observations[2,3] and by the present observation of the texture composed of zig-zag defects and isolated inversion lines (Fig.2). We used the cell of the thickness of about 10μm filled with the ZLI 3774 liquid crystal exhibiting the smectic C* phase between the temperatures from -30°C to 62°C. The glass surfaces with ITO electrodes were coated by SiO. When a small dc voltage, of about 2V, was applied on the cell the inversion lines which are present in the sample start to move (Fig.3) or new inversion lines are created on the zig-zag defects. The movement of inversion lines is the consequence of the reorientation of the **t**-vector on the upper and lower part of the chevron interface. From the two types of the **t**-vector orientations on the chevron interface shown in Fig.1 that one is preferred which gives the molecular spontaneous polarization oriented generally in the electric field direction[1,9]. Because the reorientation starts on the chevron interface the anchoring energy of the chevron interface γ is smaller as compared with the anchoring energies γ_1 of the sample surfaces.

In thicker samples the isolated inversion lines which are not directly associated with zig-zag defects can be observed. Then a small electric field with chosen polarity leads again to the movement of these isolated inversion lines and annihilation of inversion line loops leaving the sample with the twist deformation either above or below the chevron interface only. After interrupting the electric field no inversion line is created spontaneously what is the evidence that the creation of the inversion line adds to the sample energy (what is in principe the energy of the twist deformation and chevron interface energy) its self-energy and the core energy.

Nevertheless the inversion line creation can be associated with the irregularities of the interface either of the type of the mountain-like defect[10] or the changes in molecular orientations due to the presence of defects in the chevron interface.

The observation of the systems of unwinding lines together with inversion lines[7,11] shows the following features:

(a) When the inversion line occurs it changes the anchoring orientations of molecules on the chevron interface with respect to the orientations of molecules anchored on sample surfaces as seen in Fig.1. The anchoring conditions which lead to the existence of the twist deformation in the sample are called the symmetric anchoring conditions[12] (the molecules on the sample surface and chevron interface are oriented in the opposite way with respect to the observer). The parallel anchoring conditions[12] lead to the parallel anchoring of molecules on the sample surfaces and chevron interfaces. In Fig.1 the parallel anchoring conditions favour the uniform structure.

When the sample thickness is such that it permits only the existence of the system of unwinding line pairs which are relatively shifted[12] for $|Z|/2$ (Z is the helicoidal pitch) the unwinding lines occur only in the parts of the sample between surfaces and chevron interface with symmetric anchoring conditions and not in those parts with parallel anchoring conditions. As shown in the Ref.[12] the parallel anchoring conditions lead to the existence of the superimposed (unshifted) unwinding lines. The superimposed unwinding lines are, however, stable for greater sample thickness then is the stability thickness range for shifted lines[12].

In samples with shifted lines the different situations can be observed depending on the sample thickness. In this note only two cases will be mentioned. In the first case the shifted unwinding lines are either above or below the chevron interface only. Then the inversion line separates the domain with unwinding lines from the domain without any lines. In the second case the sample thickness permits the existence of shifted unwinding lines both above and below the chevron interface and their occurence is determined by the realization of the symmetric anchoring conditions. In this case the inversion line separates the domain with unwinding lines above the chevron interface from the domain where unwinding lines are below the chevron interface. Those observations seem to confirm our idea of the inversion line as a boundary between symmetric and parallel anchoring conditions.

(b) Sometimes the observation of lines reveals that the parts of the inversion and unwinding lines coincide what can be interpreted as the attraction between both lines.

This attraction tends the unwinding line to occupy the position just above the inversion line.

(c) The observations also show that the long segments of both unwinding and inversion lines are oriented along the smectic layers what is the consequence of the elastic anisotropy of the smectic liquid crystal[13].

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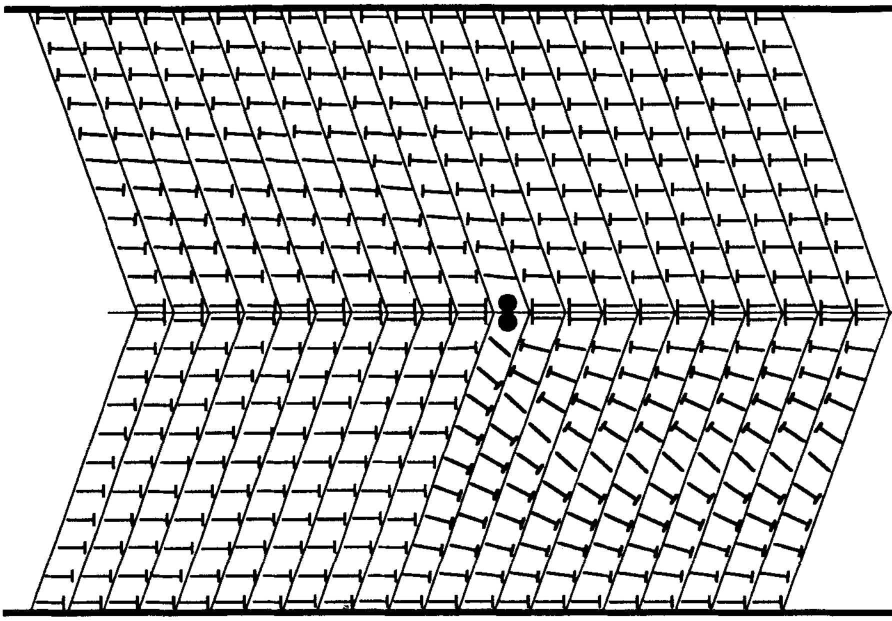
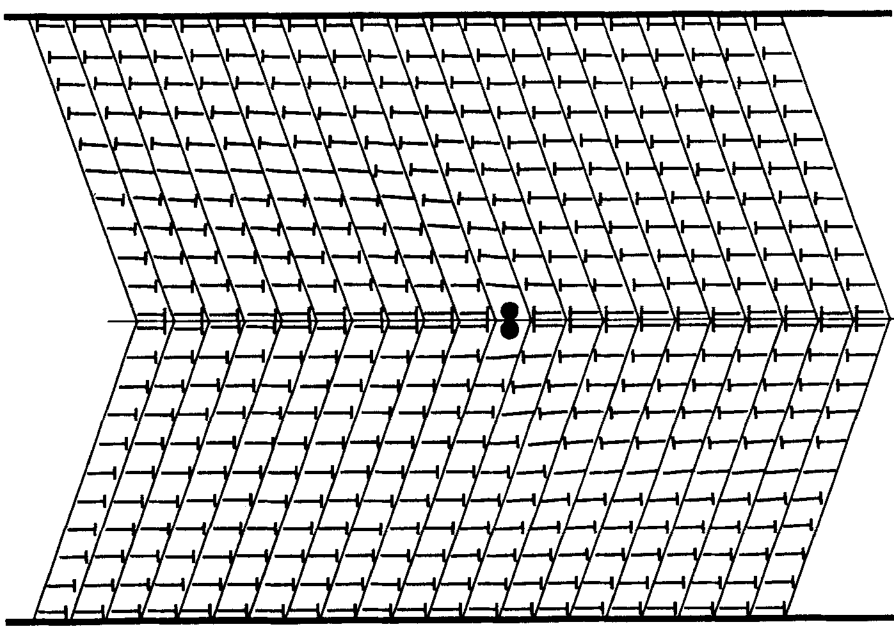


(a)



(b)

FIGURE 1: Director distribution near the inversion lines in the nail representation[8] based on the solutions describing the inversion line for the model FLC material with $\theta = 22^{o}$, $\delta = 18^{o}$, and $\Phi_o = 53^{o}$ taken from the Ref.[1], $\alpha = (B_1B_3)^{1/2}$=0.32 (B_1 and B_3 are the FLC elastic constants[6]) and D_o = D/2. (a) Asymmetric inversion line; (b) Symmetric inversion line.

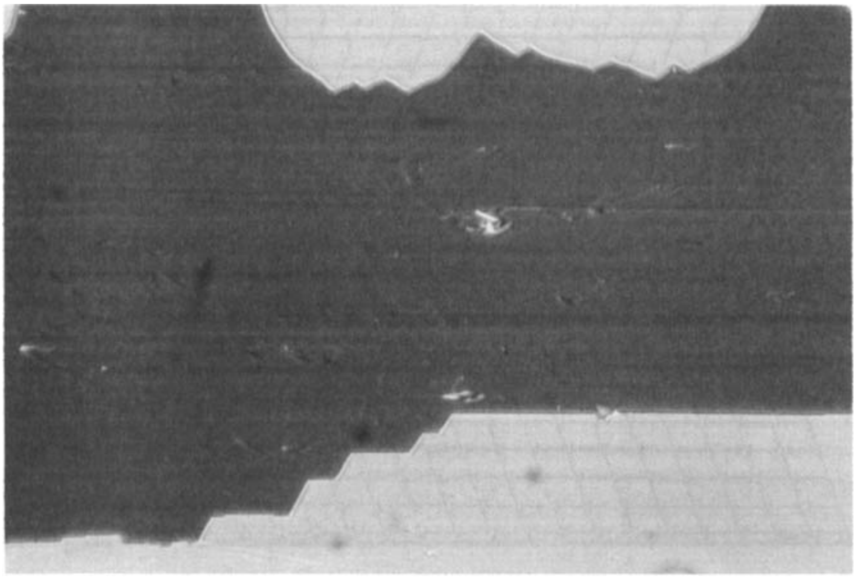


FIGURE 2: Inversion line separates two domains of different colours. See Color Plate VIII.

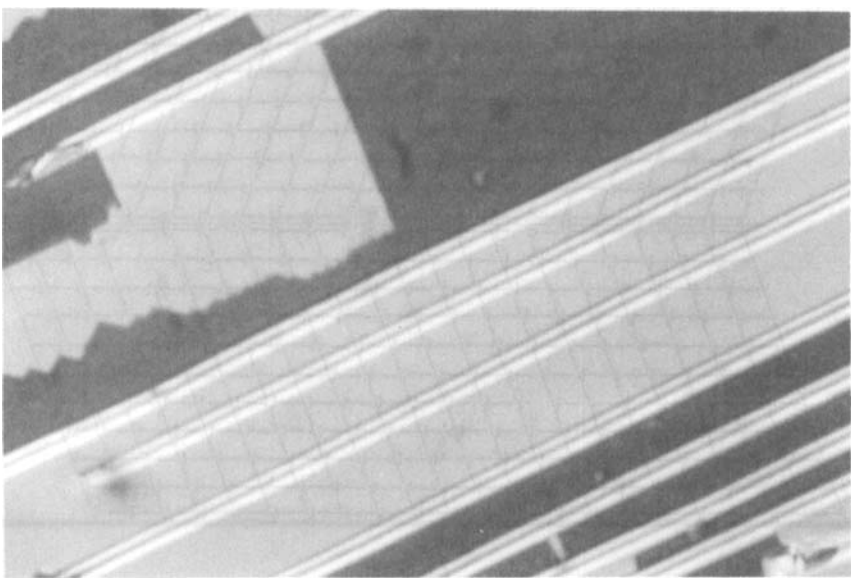


FIGURE 3: The polarity of the applied field favours the molecular orientation on one side of the inversion line. It leads to the deplacement of the inversion lines previously associated with the zig-zag defects. See Color Plate IX.