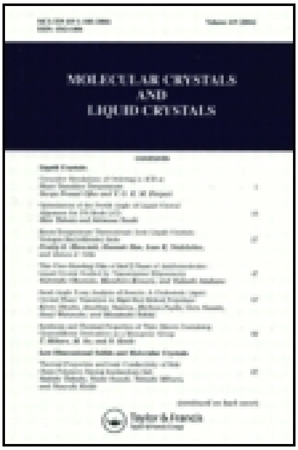

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Further Experimental Evidence for the Wall Structure of the Flexoelectric Domains in Symmetrically Weakly-Anchored MBBA Layers

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Further Experimental Evidence for the Wall Structure of the Flexoelectric Domains in Symmetrically Weakly-Anchored MBBA Layers

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An attempt for measuring of the penetration non-critical length of MBBA flexoelectric surface-induced domains is made. The disappearance of the domains into subcritical regions is related to the strong nonhomogeneity of the electric field around the gap which is able to inhibit the flexoelectric domain formation. The disappearance of the electrohydrodynamic domains generated from the flexoelectric ones, on the other hand, shows their secondary character as well. The existence of the penetration non-critical length of the flexoelectric domains is further confirmed with the observation of the corresponding supercritical influence length of side walls or air bubbles.

The behavior of the flexoelectric domains in an additionally applied magnetic field reveals their wall structure and permits the determination of the value and sign of the two MBBA flexoelectric coefficients of bend e_{3x} and splay e_{1z} when the value and sign of the total flexoelectric coefficient $(e_{1z} + e_{3x})$ are known.

INTRODUCTION

A new kind of longitudinal surface-induced flexoelectric domains arising in weakly-anchored nematic layers has recently been investigated by Hinov *et al.*[1,2] Typical features in the behavior of these domains

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were revealed to be low threshold voltages indicating the onset of their formation, being in the range of 2.5–3 V, a period varying between the nontypical values of 1.6 d and $3d$, where d is the thickness of the liquid crystal (LC) layer being under study and a strong dependence on the strength of the surface anchoring of the LC molecules. In addition, it has been also confirmed the wall structure of these flexoelectric instabilities either by creation of regularly-spaced surface disclinations separating the domains or by the hydrodynamical movement of the fluid at higher voltages which has been distinctly different in adjacent domains.

Of interest is the experimental investigation of the penetration of the flexoelectric domains into subcritical regions or their behavior under the influence of side lateral walls. This well-known and seldom used method has been employed for study of various hydrodynamic instabilities.[3–5] For instance, the experimental measurements of the correlation length of the Williams domains, performed very carefully by Ribotta,[4] unambiguously confirmed that they arise as a second-order phase transition although an abrupt increase in the deformation of these domains around and slightly above the threshold voltage has been observed.[6,7]

A valuable information about the possible static or electrohydrodynamic character of the surface-induced domains as well as for an eventual and decisive role of the initial static and periodic deformations for generation of secondary electrohydrodynamic instabilities, an important problem which has been touched on still in 1973 by Helfrich,[8] can be obtained either from the existence or disappearance of the penetration length which characterizes the attenuation of the flexoelectric domains into the subcritical regions or from their behavior under the influence of side lateral walls leading to the existence of the so-called supercritical influence length.[5] The flexoelectric domains were further investigated under the influence of an additionally magnetic field applied in such a way to act in opposite direction of the dielectric torques and which was capable to reveal again the static or electrohydrodynamic character of the surface-induced domains and to permit a numerical evaluation of the two flexoelectric coefficients of bend e_{3x} and splay e_{1z} of the nematic being under study (in our case MBBA) when the sign and the magnitude of the total flexoelectric coefficient $(e_{1z} + e_{3x})$ are known.[9–11] Finally, possible quadrupolar contributions and the eventual possible role of the surface polarization for the flexoelectric domain creation are briefly discussed.

EXPERIMENTAL RESULTS

I. Non-critical penetration length of the flexoelectric domains and of the electrohydrodynamic ones generated from the static flexoelectric deformations[12]

The observation of the coherence (or correlation) length of the flexoelectric surface-induced domains requires the application of critical and subcritical voltages across two adjacent regions of the LC under study (in our case MBBA). The two regions should be separated by discontinuity in the conductive layer which is necessary to be made parallel to the long axis of the domains and to be with a size much below the roll diameter.[4] In this way one of the confining glass plates is divided into two independent and conductive parts while the other glass plate is common and usually is connected to a ground. Moreover, the electric field is strongly inhomogeneous around the gap as has been unambiguously confirmed by Ribotta[4] who measured the maximal LC deformations in this region due to the Williams instability.

The observation of an eventual penetration depth of the surface-induced flexoelectric domains into subcritical regions is facilitated from their static character around the threshold. On the other hand, the strong dependence of the flexoelectric domains on the homogeneity of the electric field[13] together with their formation in the cathode region whatever to be the kind of the weak surface anchoring of the LC layers being under investigation: weakly-anchored nematic layers[1,2] or asymmetrically strong-weak anchored MBBA films[13,14] can reveal in detail the non-homogeneity of the electric field. Accordingly, the strong disturbance of the surface-induced domains around the gap clearly pointed out a 200 microns region over which the electric field was strongly non-homogeneous (Figure 1) (note that the discontinuity was made on the cathode). The flexoelectric domain behavior was quite different however, when the gap was made on the anode. In this case the disturbance of the flexoelectric domains was over only one roll diameter (see the bright line in Figure 2) due to the long distance of the cathode from the anode.

The accuracy of the apparatus utilized in our experiment permitted variations of the reduced quantity $\epsilon = (V_c^2 - V^2)/V_c^2$, introduced by Ribotta, between 0.08 and 1 i.e. the subcritical voltages attainable in the experiment performed by Ribotta[4] have been much closer to the corresponding threshold voltages indicating the onset either of the Williams domains or the chevrons. However, the subcritical voltages being

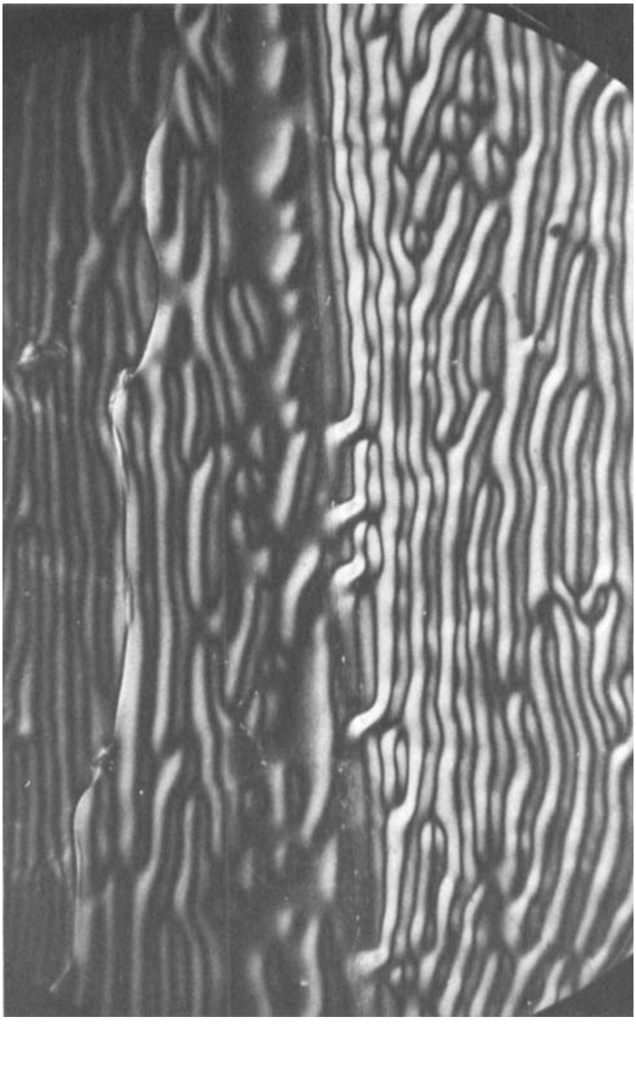

FIGURE 1 A strong disturbance of the surface-induced flexoelectric domains around the cutting line in the conductive layer of the cathode in a symmetrical weakly-anchored (42 μm) MBBA film when the one of the two parts of the LC layer is subjected to 3.5 V (see the top side of the photo) and the other part to 4 V due to the strong nonhomogeneity of the electric field in this region; A 16° $n_0 \perp P$, the short side of the photo corresponds to 1350 μm.

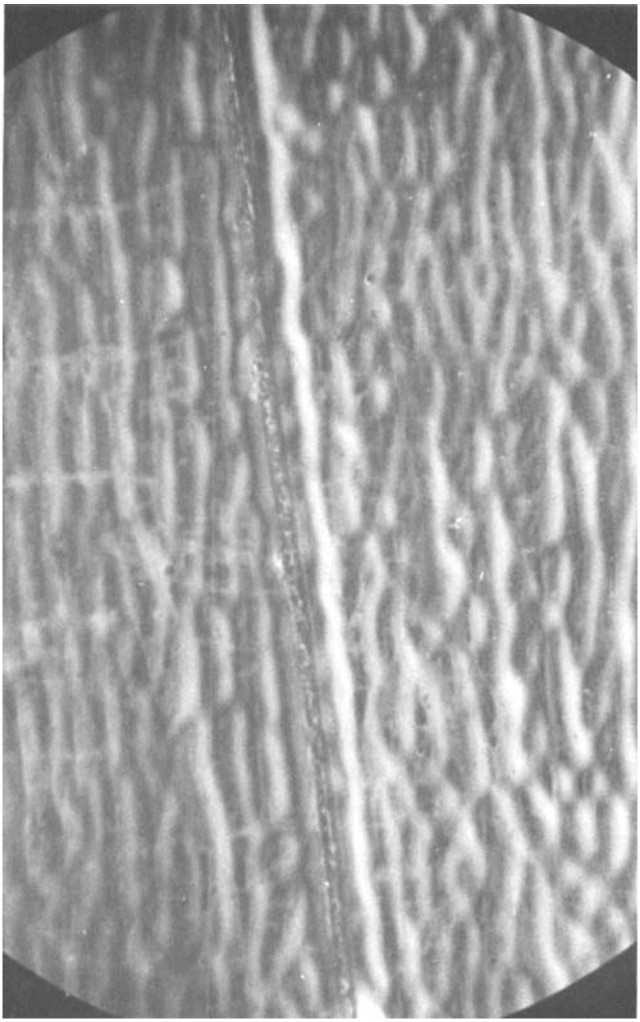

FIGURE 2 A slight disturbance of the surface-induced flexoelectric domains around the cutting line in the conductive layer of the anode in a symmetrical weakly-anchored (42 μm) MBBA film when the two parts of the LC layer are subjected to a supercritical voltage ($U = 3$ V): *A* 16° $n_0 \perp P$, the short side of the photo corresponds to 1350 μm.

applied across the MBBA layers in our study were sufficiently close to the threshold voltage in order to permit the easy observation of the penetration of the domains into the subcritical regions (see also Figure 3 in Ref. 4).

Our experimental results obtained after the investigation of many nematic MBBA layers with various thicknesses and for different strength of the voltages applied across the two parts of the layers: critical or above-critical and subcritical clearly pointed out that the static flexoelectric domains as well as the hydrodynamic ones generated from the initial flexoelectric deformations do not penetrate into the subcritical regions. For instance, the careful scrutiny of one typical picture illustrated in Figure 3 has revealed that the domain structure ends with a surface disclination before the gap followed by a smooth LC relaxation over one domain length. The removing of the domain from the discontinuity made in the conductive layer is probably due to the inhomogeneity in the electric field inhibiting the domain formation in this region (see also the bright line in Figure 2).

DISCUSSION

To understand the non-penetration of the flexoelectric domains into the subcritical regions it is necessary to discuss the main differences between the Williams domains penetrating at nearly the same experimental conditions and the flexoelectric ones. Let us first note, that the Williams domains arise as a well-defined second-order phase transition[4] while the finite θ, φ flexoelectric deformations around the threshold have revealed the first-order phase transitional character of the surface-induced domains. This untypical phase transition for a domain formation is probably due to the wall structure of the flexoelectric instability requiring the formation of inverse relaxational elastic walls terminating with surface coreless disclinations[1,2,13–18] in order to be avoided the plane discontinuity in the molecular orientation between adjacent domains (note that the formation of a single wall is a second-order phase transition[15]).

The theoretical and experimental results concerning the well-known first-order nematic–isotropic phase transition widely-studied during the past ten years[19–28] unambiguously pointed out that the penetration lengths even for this special case do exist.[23,25,27,28] In addition, the results of Tarczon and Miyano[27] demonstrate a decreasing of the order parameter in the above-critical regions (T, T_c) which should be slower

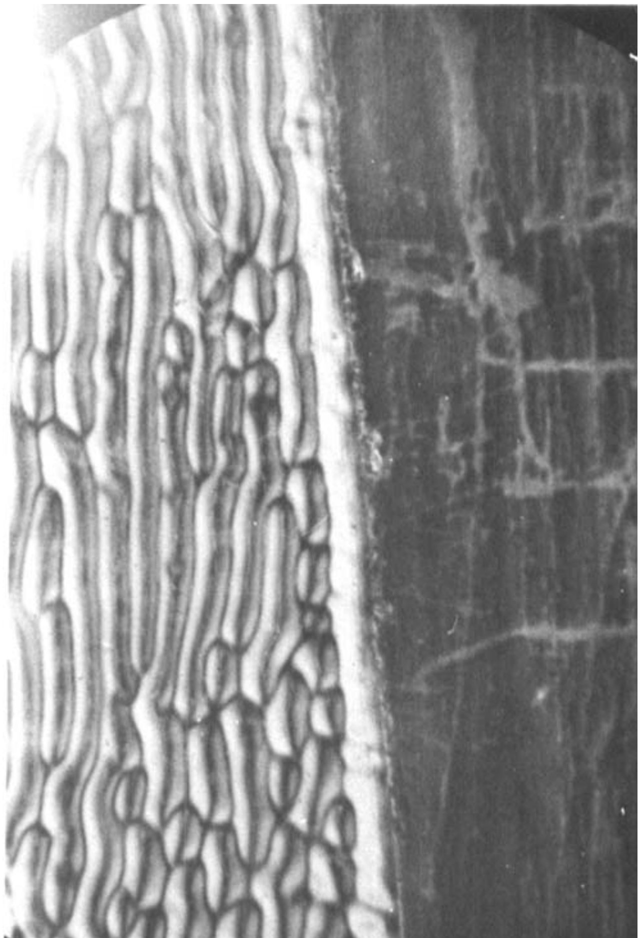

FIGURE 3 Non-existence of the non-critical penetration length of surface-induced flexoelectric domains in a MBBA film (42 μm) when the one of the two parts of the LC layer is subjected to 5 V and the other part to 2.4 V (the threshold voltage was around 2.5 V); *A* 16° $n_0 \perp P$, the short side of the photo corresponds to 1350 μm.

for the case of first-order phase transition ($b \neq 0$): $|dQ/dz|_{b\neq 0} < |dQ/dz|_{b=0}$ (this important result can be also obtained from detailed theoretical calculations[28]).

In analogy with this typical first-order phase transition (the above-critical region corresponds to a subcritical region where $E_c > E$) it is clear that the attenuation of the flexoelectric domains into the subcritical regions should be slower in comparison, for instance, with the Williams domains which arise like a second-order phase transition[4] (this is also true for the influence of side lateral walls[5]) i.e. such a wall should influence more flexoelectric rolls in comparison again with the Williams domains[4]). On the other hand, the deeper penetration of the flexoelectric domains would facilitate their observation for higher values of the reduced quantity ϵ as well.[4] So the disappearance of the flexoelectric domains into the subcritical regions cannot be related to the experimental fact which shows that they arise as a well-defined first-order phase transition.[12] It seems that the penetration of the flexoelectric domains into the subcritical regions is strongly inhibited by the discontinuity when it is made on the cathode where arise the surface-induced domains as well as by the strong non-homogeneity of the electric field around the gap (the discontinuity in the conductive layer can be made either on anode or on cathode). Let us at this point emphasize that most of the experimental and theoretical investigations of various flexoelectric phenomena have been made under the essential suggestion for homogeneity of the electric field having been used.[29–33] On the other hand Derzhanski and Petrov[34] obtained a simple covariant expression for the volume flexoelectric molecular field:

$$\mathbf{h}_f = (e_{1z} - e_{3x})[\mathbf{E}\ \mathrm{div}\mathbf{n} - \mathrm{Grad}\ \mathbf{n}\ \mathbf{E}] - (e_{1z} + e_{3x})\ \mathbf{n}\ \mathrm{Grad}\ \mathbf{E} \quad (1)$$

which clearly relates the domain formation (inhomogeneous distribution of the nematic director) to the homogeneity of the electric field. This formula shows as well that the flexoelectric domain formation can be seriously impeded and in some cases can be even entirely inhibited by the action of the flexoelectric gradient torques.[34]

The disappearance of the surface-induced flexoelectric domains into the subcritical regions due to the strong nonhomogeneity of the electric field around the gap proofs first, their static character (the electrohydrodynamic domains penetrate in spite of the inhomogeneity of the electric field[4]) and second, the secondary character of the electrohydrodynamic domains generated from the flexoelectric ones (they cannot penetrate into the subcritical regions although they are hydrodynamic).

To confirm the penetration of the flexoelectric domains into subcritical regions at a relatively homogeneous electric field we have investigated the domain behavior near side lateral walls[5] in an asymmetrically strong–weak anchored MBBA layer[13,14] or near occassionally formed air bubbles for the case of symmetrically weakly-anchored MBBA layers.

The attenuation of the flexoelectric domains near lateral side walls (or spacers) (Figures 4a and 4b) or around holes (Figures 5a and 5b) clearly confirms first, the existence of a supercritical influence length and consequently of a non-critical penetration length of the flexoelectric domains requiring a high homogeneity of the electric field around the gap which is very hard to be achieved and second, the secondary character of the electrohydrodynamic instability generated from the flexoelectric one which attenuates far away from the side walls (Figure 4b) while the Williams domains attenuate very near to such walls (see Figure 4 in Ref. 4).

II. Behavior of the flexoelectric domains in an additionally applied magnetic field—a second experimental evidence for the wall structure of these instabilities

The competition between the dielectric torques leading to unperiodic orientation or deformation of the LC with respect to the boundary conditions and the flexoelectric bulk torques according to the one-dimensional and two-dimensional flexoelectric theories developed by Meyer[29,30] and Fan[31] and Bobylev *et al.*[32,33] determines smooth and periodic flexoelectric deformations when the following important inequality holds:

$$\frac{(e_{1z} - e_{3x})^2}{K} > \frac{|\Delta\epsilon|}{4\pi} \tag{2}$$

(note the isotropic elasticity)

where e_{1z} and e_{3x} are the flexoelectric coefficient of splay and bend, originally introduced for the first time by Meyer,[29,30] K is the mean elastic coefficient and $|\Delta\epsilon|$ is the absolute value of the dielectric anisotropy of the LC.

Physically this constraint is clear and shows that above certain value of the dielectric anisotropy the dielectric torques are stronger over the flexoelectric ones and the development of periodic flexoelectric deformations is not possible. However, it is easy to understand that this constraint is valid only for a smooth periodic flexoelectric deformation.

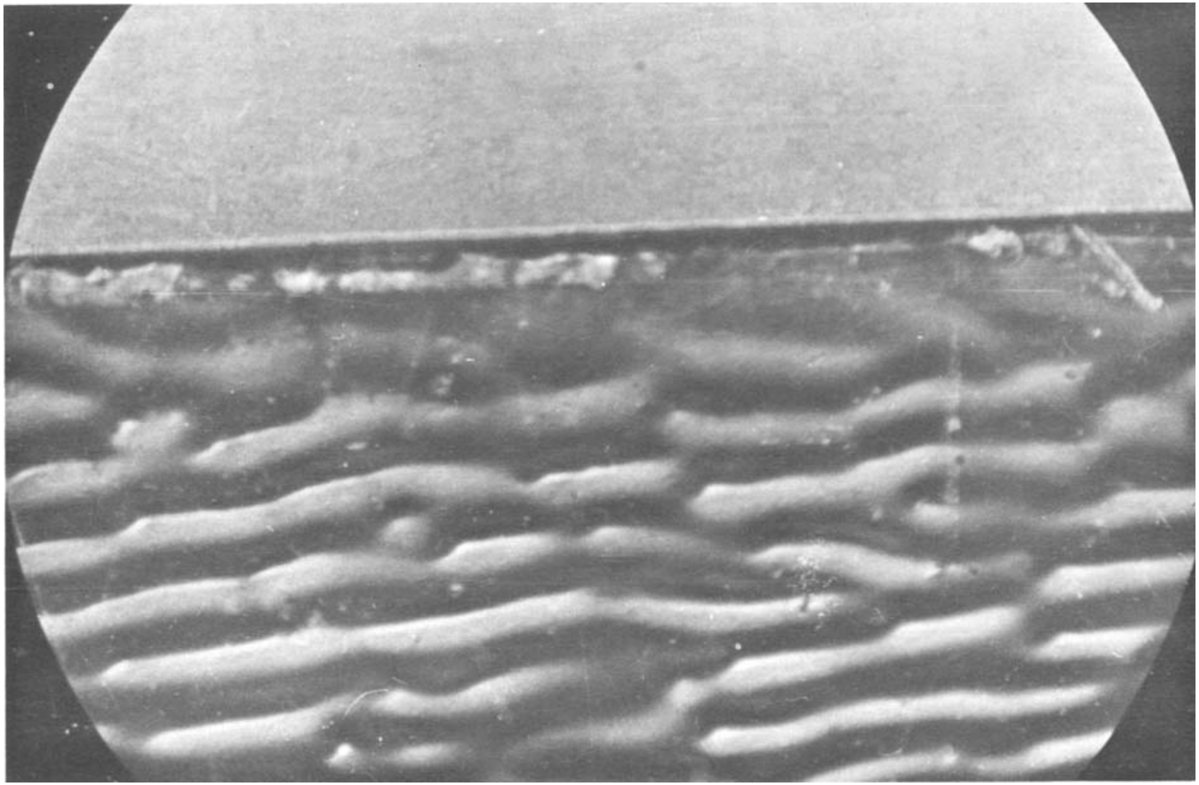

FIGURE 4a Supercritical influence length of a side lateral wall on flexoelectric surface-induced domains created in an asymmetrically strong–weak anchored MBBA layer (76 μm) subjected to 3.5 V, initially crossed nicols, $A \parallel n_0 \perp P$, the analyzer rotation angle $\varphi \simeq 20°$; the short side of the photo corresponds to 1350 μm.

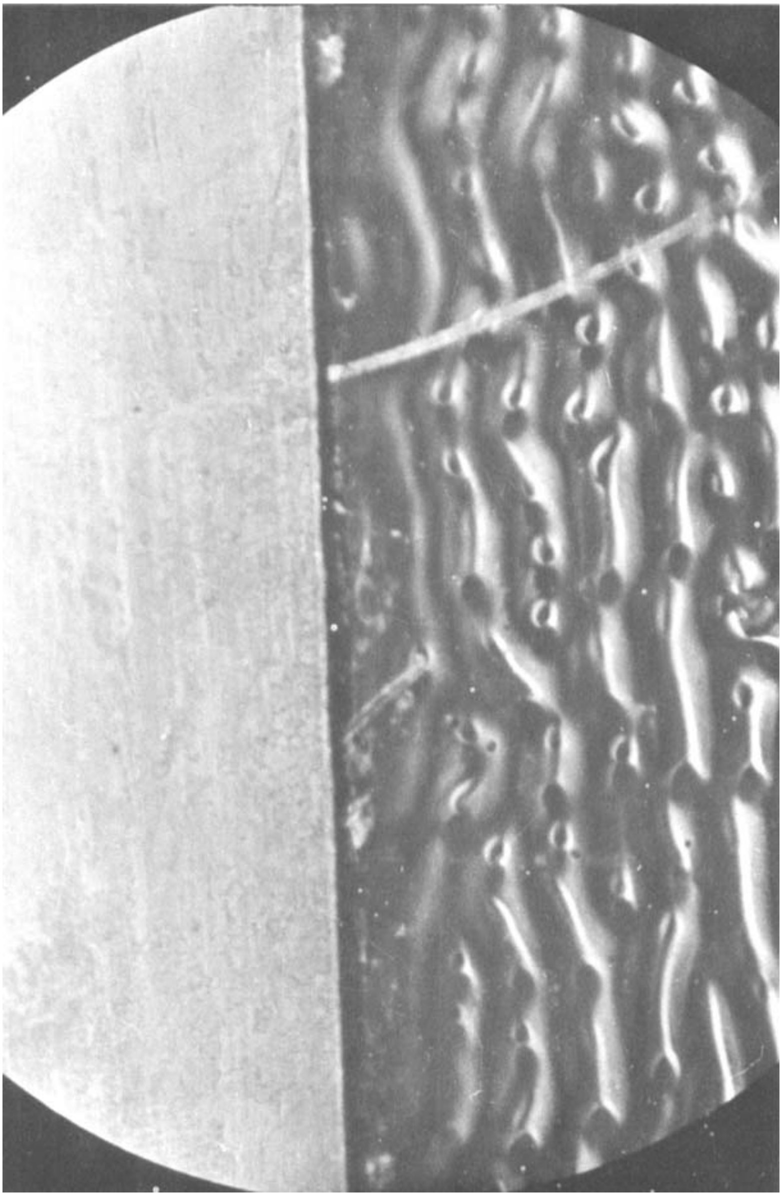

FIGURE 4b The same LC layer subjected to 5 V reveals the existence of a supercritical influence length of a side lateral wall on the secondary electrohydrodynamic instability generated from the flexoelectric one.

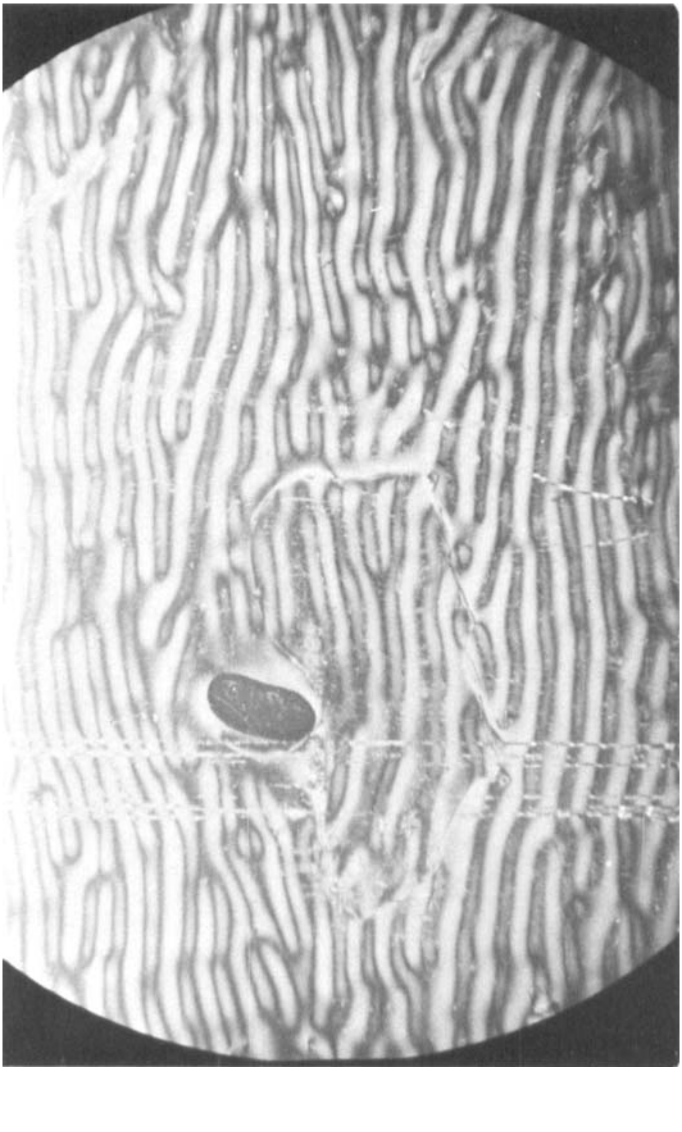

FIGURE 5a Supercritical influence length of air bubbles on flexoelectric surface-induced domains including a hydrodynamic movement of the fluid in a symmetrical weakly-anchored MBBA layer (46 μm) subjected to 4 V; crossed nicols, the short side of the photo corresponds to 1350 μm.

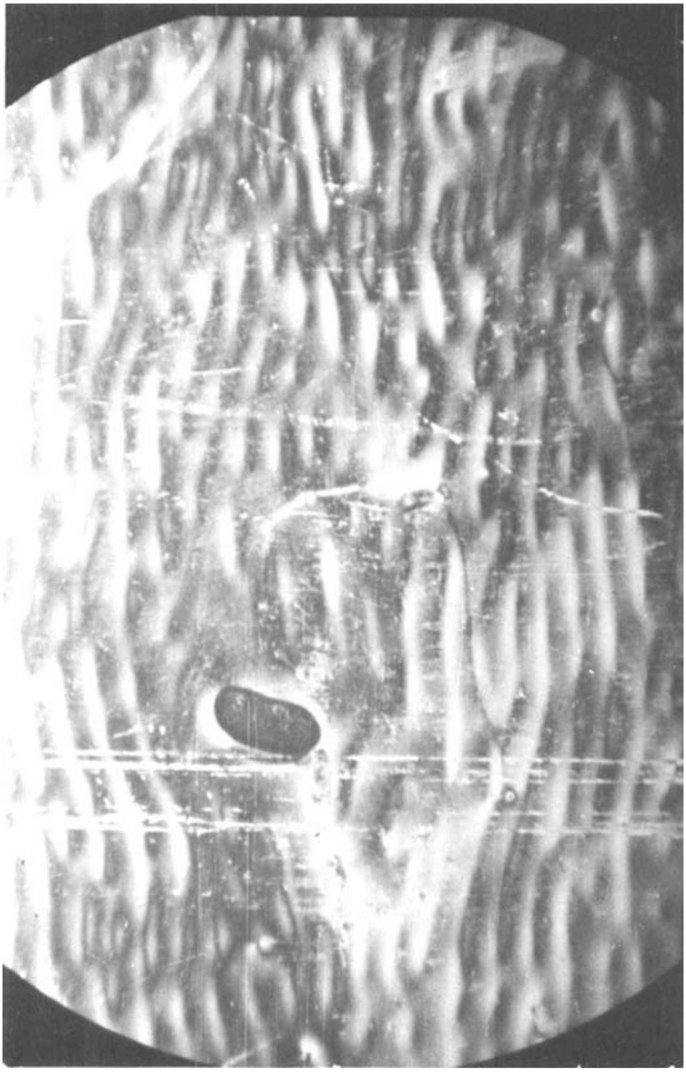

FIGURE 5b The same LC layer with a suppressed hydrodynamic due to the application of a.c. voltage ($U = 20$ V, $f = 20$ kHz).

When the opposite inequality holds:

$$\frac{(e_{1z} - e_{3x})^2}{K} < \frac{|\Delta\epsilon|}{4\pi} \tag{3}$$

flexoelectric deformations with a wall structure can arise in nematic layers subjected to a d.c. or low-frequency electric field.[13,14] The wall structure itself is not forbidden for nematic layers and can arise under the influence of magnetic or electric fields.[35–39] The appearance of the flexoelectric walls depends strongly on the adjustment of the LC orientation in adjacent domains which according to our experimental results is possible either for weakly-anchored nematic layers[1,2] or in the important case of asymmetrically strong-weak anchoring of the nematic layers[13,14] which permits the formation of very low-energy surface coreless disclinations. In addition, it is known that a symmetrical surface disclination introduced in a previously deformed nematic layer can lead to a pronounced extrinsic bulk asymmetry in the LC orientation[17] which is very favorable for the creation of flexoelectric walls with opposite twist in the adjacent domains.[13,14] Unfortunately, less is known about the LC deformations matching the bulk LC realignment between adjacent flexoelectric walls. The detailed LC orientation in these regions is not clear and probably includes all the possible LC deformations of splay, bend and twist in such a way to minimize the elastic energy.

The validity of the inequality (3) can be easily verified by means of an additionally magnetic field applied in such a way to flexoelectric domains to act in the opposite direction of the dielectric torques.

1. Experimental results. The experimental set-up is described elsewhere.[1] A previously prepared MBBA nematic thin layer is subjected under the simultaneous action of a d.c. electric field and a magnetic field both applied along the normal to the glass plates of the LC cell.

The integral intensity of the light transmitted through such a layer versus the magnetic field for various d.c. voltages, applied across the nematic layer under study, is shown in Figure 6. The first experimental curve is obtained for a subthreshold voltage (2 V) (the appearance of the flexoelectric domains was around 3 V) and shows the orienting action of the magnetic field only. However, the experimental curves are quite different for above threshold voltages when well-defined flexoelectric domains exist. The distinct resonance character of these curves (already obtained by us in previous experimental measurements without giving any interpretation[1]) is due only to the enhancement of the

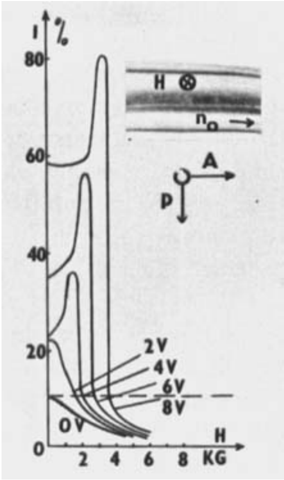

FIGURE 6 Light intensity versus the magnetic field for various values of the d.c. voltage applied across a weakly-anchored MBBA layer (15 μm). In the figure is also shown the correct position between the long axis of the domains and the two nicols. The dotted line shows the compensation between the dielectric and magnetic field torques.

flexoelectric deformations for the case when the dielectric torques are canceled by the magnetic ones. Consequently, the significant rise in the intensity of the transmitted light is connected with the corresponding rise in the φ-azimuthal flexoelectric deformations.

It is clear that the magnetic field can ENHANCE the flexoelectric deformations up to the following equality:

$$-\frac{|\Delta\epsilon|}{4\pi}E^2 + \Delta\chi H^2 = 0 \tag{4}$$

for the extremely important case of a homogeneous electric field.[40] This relation according to the well-known theoretical results obtained by Helfrich[41] can simply yield an important combination between the flexoelectric coefficients of splay e_{1z} and bend e_{3x}:

$$\left(\frac{e_{3x}^2}{K_{33}} - \frac{e_{1z}^2}{K_{11}}\right) = -\frac{|\Delta\epsilon|}{4\pi} + \frac{\Delta\chi H_c^2}{E^2} \tag{5}$$

where $|\Delta\epsilon| = |\epsilon_\perp - \epsilon_\parallel|$ is the anisotropy of a dielectrically "clamped" LC layer and H_c causes the maximal enhancement of the flexoelectric deformations. Of interest is to note that the Eq. (5) can be experimentally verified for each type of flexoelectric deformations when the electric field is homogeneous.[41]

The resonance character of the experimental curves can be obtained only for one unique arrangement between the long axis of the flexoelectric domains and the two nicols (certainly the nicols can change their places) (Figure 6). Each other possible location of the nicols with respect to the long axis of the flexoelectric walls would drastically smear the resonance shape of the curves. For instance, this can be demonstrated when the analyzer (or the polarizer) are rotated at a certain azimuthal angle in such a way to reveal the double periodicity of the flexoelectric domains which is resulted in the appearance of dark and bright bands.[1,2,13,14]

The relation (5) shows that the ratio E/H_c should be with a constant magnitude. In our experiment, however, this ratio has slightly changed due to the formation of the double electric layers near the electrodes. Moreover, the dotted line in Figure 6 indicates the total erase of the flexoelectric domains by the magnetic torques which permits the numerical estimation of the ratio E/H_c. For instance, our result obtained during the experimental measurements is close to the magnitude of E/H_c having been measured by Rao *et al.*[42] also for the case of MBBA: 0.52–0.53.

2. Determination of the MBBA flexoelectric coefficient of splay e_{1z} *and bend* e_{3x}. In order to estimate the value of $(e_{1z}-e_{3x})^2$ it is necessary to know a second possible relation between the two flexoelectric coefficients of splay e_{1z} and bend e_{3x}. It is useful to utilize the total flexoelectric coefficient which represents the sum of the two flexoelectric coefficients e_{1z} and e_{3x}: $(e_{1z} + e_{3x})$ because it had been measured to be positive and with a value between 4×10^{-4} and 8×10^{-4} dyn$^{1/2}$.[9,10,43,44] Then one should solve the following two equations describing the flexoelectric coefficients of splay e_{1z} and bend e_{3x}:

$$\frac{e_{3x}^2}{K_{33}} - \frac{e_{1z}^2}{K_{11}} = \frac{\Delta\chi H_c^2}{E^2} - \frac{|\Delta\epsilon|}{4\pi}, \quad e_{1z} + e_{3x} = p \tag{6}$$

The final algebraic equation describing, for instance the flexoelectric coefficient of bend e_{3x} has the following usual quadratic form:

$$e_{3x}^2 + (b/a)e_{3x} + (c/a) = 0 \tag{7}$$

with

$$(b/a) = -\frac{2K_{33}p}{K_{33} - K_{11}}$$

$$(c/a) = \frac{K_{33}K_{11}}{K_{33} - K_{11}}\left[\frac{\Delta\chi H_c^2}{E^2} - \frac{|\Delta\epsilon|}{4\pi}\right] + \frac{K_{33}}{K_{33} - K_{11}}p^2$$

The eventual possible sign of the flexoelectric coefficient of bend e_{3x} (and consequently of splay e_{1z}) can be determined via the eventual signs of the total flexoelectric coefficient $(e_{1z} + e_{3x})$ and of the difference between the elastic coefficients of bend K_{33} and splay K_{11}.

The difference between $\Delta\chi H_c^2/E^2$ and $|\Delta\epsilon|/4\pi$ was obtained from the experimental curve for the case of 4 V when the flexoelectric domains are still static and the double electric layers are still weak (Figure 6). In this manner the magnitude of the magnetic field H_c was measured to be 2 kG and the threshold voltage of 4 V was decreased by 0.5 V on account of the inverse voltage due to the double electric layers. The other material constants involving in the problem under consideration were chosen to be in accordance with the last measurements performed to date at room temperature ($T = 21°C$):

$$|\Delta\epsilon| = 0.6,^{45} \quad \Delta\chi = 0.9 \times 10^{-7\,46}$$
$$K_{11} = 5.6 \times 10^{-7}\ \text{dyne},^{47} \quad K_{33} = 8.2 \times 10^{-7}\ \text{dyne}^{47}$$

Finally the thickness of the LC layer under study was measured to be around 15 microns.

The solution of the quadratic Eq. (7) is presented in Figure 7 and the corresponding solution for the flexoelectric coefficient of splay in Fig-

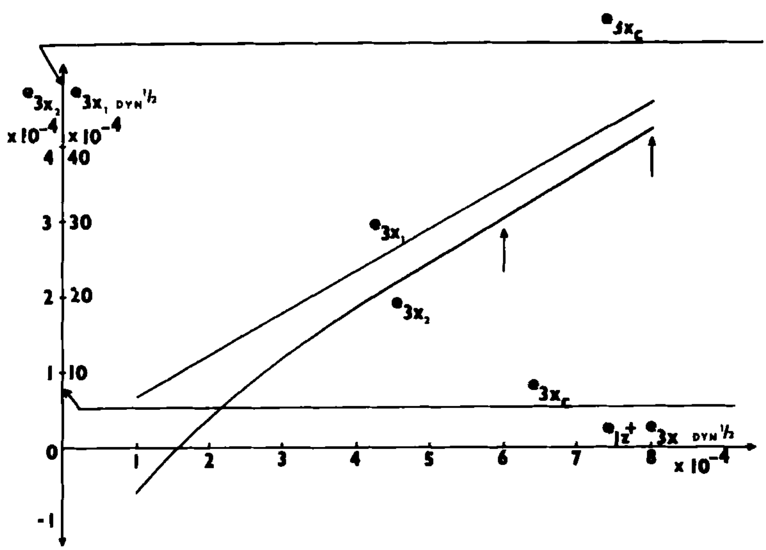

FIGURE 7 The two MBBA flexoelectric coefficients of bend $(e_{3x})_1$ and $(e_{3x})_2$ calculated from the algebraic equation according to the experimental results and plotted as a function of the total MBBA flexoelectric coefficient $(e_{1z} + e_{3x})$. In the figure is also shown the critical value of the flexoelectric coefficient of bend e_{3xc} calculated from the Helfrich's theory.[41]

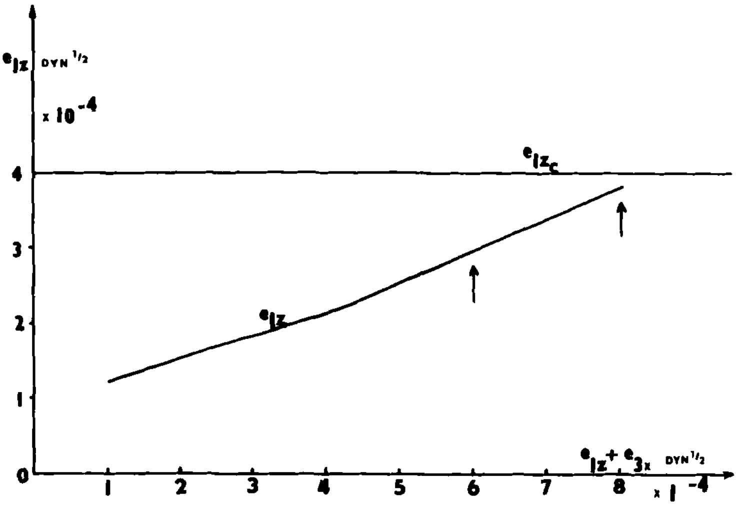

FIGURE 8 The MBBA flexoelectric coefficient of splay e_{1z} calculated from the algebraic equation according to the experimental results and plotted as a function of the total MBBA flexoelectric coefficient $(e_{1z} + e_{3x})$. In the figure is also shown the critical value of the flexoelectric coefficient of splay e_{1zc} calculated from the Helfrich's theory.[41]

ure 8. Let us stress here that the one root of the flexoelectric coefficient of bend $(e_{3x})_1$ resp. of splay $(e_{1z})_1$ are physically meaningless due to the constraint posed by the relation between the dielectric and flexoelectric tensor elements:

$$e_{3x}^2 < K_{33}\frac{\epsilon_\perp^f - 1}{4\pi}, \quad e_{1z}^2 < K_{11}\frac{\epsilon_\parallel^f - 1}{4\pi} \tag{8}$$

where ϵ^f are the free dielectric constants to be observed with an "unclamped" orientation pattern which is free to assume the splay and bend minimizing of the free energy.[41] The magnitude of the other two roots of the differential equations describing either the flexoelectric coefficient of bend e_{3x} or the flexoelectric coefficient of splay e_{1z} clearly confirmed the wall structure of the MBBA flexoelectric deformations which exist under the following condition:

$$\frac{|\Delta\epsilon|}{4\pi}\frac{K}{(e_{3x}+e_{1z})^2} < 1 \tag{9}$$

which holds when the additional and very important inequality is valid:

$$\frac{\Delta\chi H_c^2}{E^2} \ll \frac{|\Delta\epsilon|}{4\pi} \tag{10}$$

The inequality (9) is certainly fulfilled for any value of the total flexoelectric coefficient $(e_{1z} + e_{3x})$ higher than 2×10^{-4} dyne$^{1/2}$.

For the more general case when the correlation between the values of $H_c^2(\Delta\chi/E^2)$ and $|\Delta\chi|/4\pi$ is not known flexoelectric walls can exist when the following inequality:

$$\frac{(e_{1z} - e_{3x})^2}{K} < \left[\frac{\Delta\chi H_c^2}{E^2} - \frac{|\Delta\epsilon|}{4\pi}\right]^2 \frac{K}{(e_{1z} + e_{3x})^2} \qquad (11)$$

is valid for the simplest case of isotropic elasticity and H_c being the resonance value of the additional magnetic field applied to enhance maximally the flexoelectric deformations. Note that this inequality holds for every possible type of boundary conditions which permit the flexoelectric domain appearance.

The experimental results revealed for the first time the positive sign of the two MBBA flexoelectric coefficients of splay and bend for the case when the total flexoelectric coefficient $(e_{1z} + e_{3x})$ is positive and greater than 2×10^{-4} dyn$^{1/2}$—one condition being in accordance with all the experimental results obtained for MBBA to date. Moreover, our experimental results clearly confirmed that the absolute value of the total flexoelectric coefficient $(e_{1z} + e_{3x})$ is well above the value of the corresponding difference between these two MBBA flexoelectric coefficients $(e_{1z} - e_{3x})$ which unambiguously demonstrates quadrupolar contributions in the magnitude of the two flexoelectric coefficients for the MBBA case.[48,49]

3. Possible role of the surface polarization for the flexoelectric domain formation. The initial formation of the surface-induced domains is closely linked with the electrode treatment influencing both the strength of the surface anchoring of the LC molecules and the size, sign and distribution of the space charges in the LC layer under study. All these experimental facts important for the appearance and development of the surface-induced domains turn our attention to a possible role of the surface polarization originally introduced for the first time in the flexoelectric problems by Prost and Pershan[10] and investigated in detail by Petrov and Derzhanski[50,51] (various problems depending on the surface polarization have also been discussed by Prost and Marcerou,[49] Parsons[23] and Naemura[52]).

The surface polarization essential for homeotropic or high-tilted nematic layers cannot produce itself electrically surface-induced domains including in part a periodic variation of the nematic director in planes parallel to the electrodes since this polarization can influence only the θ-polar deformation depending on Z i.e. normal to the glass plates. The flexoelectricity, on the contrary, can produce such type of a LC deformation which can be easily understood, for instance, in the framework of the flexoelectric molecular field [see Eq. (2)]. This important conclusion is confirmed by the flexoelectric domain behavior in an additionally applied magnetic field which can influence not only θ-polar but also φ-azimuthal flexoelectric deformations, since they are coupled.

The surface polarization, however, can change the threshold voltage and the period of the flexoelectric instability. Furthermore, the surface polarization is not important in general for nearly-planar nematic layers with strong–weak anchoring in which flexoelectric surface-induced domains do exist.

CONCLUSIONS

The non-existence of a penetration non-critical length of the electrically surface-induced domains in weakly-anchored MBBA films in our opinion is due only to the strong nonhomogeneity of the electric field around the discontinuity in the conductive layer which confirms first, the real flexoelectric character of these domains (the nonhomogeneity of the electric fields makes difficult the appearance of periodic flexoelectric deformations) and second, their static nature around the threshold (the electrohydrodynamic instability do exist in spite of the nonhomogeneity of the electric field[4]).

Further, the non-existence of the penetration non-critical length of the electrohydrodynamic instabilities generated from the flexoelectric ones demonstrates the secondary character of these domains which do not exist without the appearance of the flexoelectric instability.

The existence of the penetration non-critical length for the case of a homogeneous electric field was further confirmed by the existence of the corresponding super-critical influence length[5] of side lateral walls or holes on the flexoelectric instability. Again was confirmed the secondary character of the electrohydrodynamic instability arising from the flexoelectric one.

The behavior of the flexoelectric domains in an additionally magnetic field applied in such a way to act in opposite direction of the dielectric torques further confirmed the wall structure of the flexoelectric domains and revealed the physical causes for their formation. The possible sign and magnitude of the two flexoelectric coefficients of splay

e_{1z} and bend e_{3x} can be estimated on the basis of the flexoelectric domain behavior in an additionally applied magnetic field on condition that provided the sign and the magnitude of the total flexoelectric coefficient $(e_{1z} + e_{3x})$ to be known. For instance, the experimental results reveal the positive sign of the two MBBA flexoelectric coefficients which should be in the same order of magnitude when the total flexoelectric coefficient is positive and greater than 2×10^{-4} dyn$^{1/2}$.

The experimental results show as well the insignificant role of the surface polarization for the flexoelectric domain formation. Finally, possible quadrupolar contributions in the flexoelectric phenomenon under study are briefly discussed.

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