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LONGITUDINAL FLEXOELECTRIC DOMAINS IN *BMAOB* NEMATIC LAYERS UNDER THE JOINT ACTION OF DC AND AC VOLTAGES

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The d.c. voltage threshold (U_c) and wave number (q) of the flexoelectric domains of Vistin'–Pikin–Bobylev have been obtained experimentally in p-n-butyl-p-methoxyazoxy–benzene (BMAOB) layers with strong-strong and strong-weak anchoring, under the joint action of increasing d.c. and a.c. voltages. A comparison of the experimental points and the theoretical curves (for a homogeneous electric field and isotropic elasticity) shows a very good fit for the d.c./a.c. voltage curves and a relatively good fit for the q/a.c. voltage curves. The values of the important material parameters are in the range already obtained by other authors. The quality of the diffraction gratings built on the basis of these domains can be considerably improved by the simultaneously application of a.c. and d.c. voltages with appropriate magnitudes.

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1. Introduction

The θ,φ-volume flexoelectric domains were observed by Vistin' in 1970 [1] and independently by Greubel and Wolff in 1971 [2]. Bobylev and Pikin [3,4] have theoretically explained the flexoelectric nature of the domains discovered by Vistin' and displaying both θ-polar and φ-azimuthal volume flexoelectric deformations. These authors have calculated the period of the domains and the threshold for their appearance; two important quantities which connect the material parameters of the liquid crystal to the value of the applied electric field. The aim of the present study is the experimental and theoretical investigation of longitudinal volume flexoelectric domains under the joint action of d.c and a.c. voltages. The solution offers a number of advantages, as follows: firstly, a comparison of the experimental points and the theoretical curves can unambiguously show the degree of the inhomogeneity of the electric field; secondly, the anisotropy of the elasticity of the liquid crystal can be found [4], thirdly, the kind of the anchoring, which can be strong or weak can be established, and so on. Also, comparison of the experimental points and the theoretical curves can give the range of values of important material parameters characterizing the liquid crystal under study, such as the dielectric anisotropy, the elastic and flexoelectric coefficients and the thickness of the liquid crystal layer.

2. Theory and experiment

The "electric enthalpy" H_E of the liquid crystal consists of three parts: elastic, flexoelectric [5-7] and dielectric, as follows:

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$$\int\limits_V \left\{ \frac{1}{2} K \left((divn)^2 + (rotn)^2 \right) - e_{1z} E.ndivn - e_{3x} (rotn \text{ x } n) - \frac{|\Delta\varepsilon|}{8\pi} \left((nxE)^2 + (nxE_{\sim})^2 \right) \right\} dV \quad (1)$$

where n is the nematic director, K is the mean elastic coefficient, e_{1z} end e_{3x} are the flexoelectric coefficients of splay and bend, $\Delta\varepsilon$ is the value of the dielectric anisotropy, in our case negative, E is the value of d.c. electric field and $E_{\sim}$ is the value of a.c. electric field . Additionally, it is assumed that the d.c. electric field can be inhomogeneous, which can lead to the observation of the so-called "gradient flexoelectric effect" [5]. Introducing the following components of the director n: $n_x = \cos\theta.\cos\varphi$, $n_y = \cos\theta.\sin\varphi$ and $n_z = \sin\theta$, approximating them with $n_x \sim 1$, $n_y \sim \varphi$ and $n_z \sim \theta$, and performing the well known mathematical variational procedure, we have obtained the following two differential equations:

$$\frac{\partial^2\varphi}{\partial y^2} + \frac{\partial^2\varphi}{\partial z^2} - \frac{(e_{1z} - e_{3x})E}{K} \frac{\partial\theta}{\partial y} = 0 \quad (2a)$$

$$\frac{\partial^2\theta}{\partial y^2} + \frac{\partial^2\theta}{\partial z^2} + \frac{(e_{1z} - e_{3x})E}{K} \frac{\partial\varphi}{\partial y} - \left[\frac{(e_{1z} + e_{3x})}{K} \frac{dE}{dz} + \frac{|\Delta\varepsilon|}{4\pi K} \left(E^2 + E_{\sim}^2 \right) \right] \theta = 0 \quad (2b)$$

describing the elasto-flexo-dielectric deformations inside the nematic layers. Following the solution procedure given by Bobylev and Pikin [3], we have used the solutions proposed in [3]:

$$\theta = \theta_0 \cos qy \cos\frac{\pi z}{d}, \qquad \varphi = \varphi_0 \sin qy \cos\frac{\pi z}{d} \quad (3)$$

taking into account the periodic flexoelectric deformations along the axis Y and the strong anchoring of the director n at the limiting boundaries. Finally, we have obtained a connection between E and the wave number q (see the theoretical results obtained in [3]). The minimization of E with respect to q leads to the following two important equations:

$$q_c^2 = \left(\frac{\pi}{d}\right)^2 \frac{1}{1-|\mu|} \left[|\mu| + \sqrt{1 + (1-|\mu|) \left[\frac{e_{1z} + e_{3x}}{K} \left(\frac{d}{\pi}\right)^2 \frac{dE}{dz} + \left(\frac{U_{\sim}}{U_0}\right)^2 \right]} \right] \quad (4)$$

where $|\mu| = \dfrac{|\Delta\varepsilon| K}{4\pi (e_{1z} - e_{3x})^2}$ and $U_0 = \pi \sqrt{\dfrac{4\pi K}{|\Delta\varepsilon|}}$ [3] and

$$U_c^2 = \frac{1}{P} \left(\frac{K\pi}{e_{1z} - e_{3x}} \right)^2 \left\{ \left[\left[\frac{1}{1-|\mu|} \right] (1+P) + \frac{e_{1z} + e_{3x}}{2K} \left(\frac{d}{\pi}\right)^2 \frac{dE}{dz} + \frac{1}{2} \left(\frac{U_{\sim}}{U_0}\right)^2 \right]^2 - \left[\frac{e_{1z} + e_{3x}}{2K} \left(\frac{d}{\pi}\right)^2 \frac{dE}{dz} + \frac{1}{2} \left(\frac{U_{\sim}}{U_0}\right)^2 \right]^2 \right\} \quad (5)$$

where $P = \sqrt{1 + (1-|\mu|) \left[\dfrac{e_{1z} + e_{3x}}{K} \left(\dfrac{d}{\pi}\right)^2 \dfrac{dE}{dz} + \left(\dfrac{U_{\sim}}{U_0}\right)^2 \right]}$

Equations (4) and (5) clearly show that the gradient flexoelectric term complicates the problem very much, since dE/dz depends on a concrete value of U_c at each point (see the results obtained in [5]). Consequently, we decided to drop this term and to compare the experimental and theoretical results for the case of a homogeneous electric field.

We have experimentally studied the liquid crystal BMAOB placed in a wedge-shaped cell. The glass plates were treated in such a way as to ensure strong-weak anchoring of the liquid crystal (see the description in [5], chapter 4.4). The experiment was performed with a liquid crystal film thickness of 12 μm , at room temperature and with $\Delta\varepsilon = -0.25$.

3. Results and discussion

The experimental points for the d.c./a.c. case, together with the theoretical curves obtained according to Eq. (5) are shown in Fig. 1. Initially we applied a d.c. voltage up to the appearance of the flexoelectric domains. Then we applied an a.c. voltage, keeping the d.c. voltage constant up to the disappearance of the domains. Next, keeping the same value of the a.c. voltage, we increased the d.c. voltage further, just to the re-appearance of the domains. This procedure was performed for all points shown in Fig. 1.

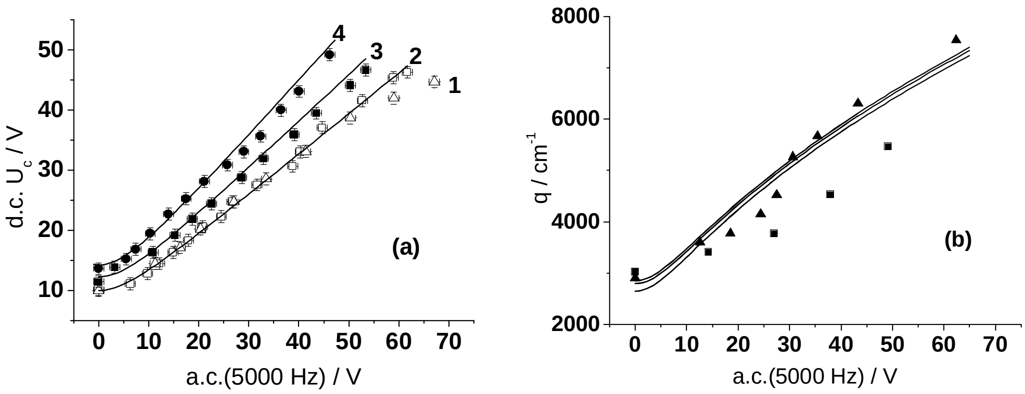

Fig. 1. The threshold voltage U_c (a) and wave number q (b) of the flexoelectric domains, as a function of a.c. voltage in a strong-strong anchored nematic layer at room temperature.

During the fitting process, the following ranges of the important parameters:

$$0.01 \le \mu \le 0.3;\ 5.10^{-7}\text{dyne} \le K \le 6.5.10^{-7}\text{dyne};\ 10^{-4}\text{dyne}^{1/2} \le (e_{1z} - e_{3x}) \le 2.10^{-4}\text{dyne}^{1/2};$$
$$5\text{V} \le U_0 \le 6.5\text{V} \qquad (6)$$

were taken into account [4]. Finally, we obtained a good fit as follows (see Fig. 1a):

Table 1. Values and dimensions of the fitting parameters.

Curves	$P_1 = K/(e_{1z}-e_{3x})$ [dyne$^{1/2}$]	$P_2=\mu$,	$P_3=U_0$ [V]
1	0.00409	0.22656	6.42
2	0.00409	0.22656	6.42
3	0.00454	0.30000	6.50
4	0.00544	0.28050	6.50

The experimental points of curves 1 and 2 (“+” or “-“ in respect of the d.c. voltage on the upper glass plate of the cell) were obtained initially, when the resistivity of the liquid crystal was higher, facilitating ion injection from the electrodes of the cell. Curves 3 and 4 were obtained four days later, when the resistivity became lower leading to an essential decrease of the injection. The corresponding experimental curves for the wave number q as a function of the a.c. voltage are shown in Fig. 1b. The fit is not so good, this is due firstly to the method used to count the domains (directly under the microscope), secondly to local variations of q, and thirdly to the inhomogeneity of the electric field. The square experimental points in Fig. 1b can not be fitted, due to the inhomogenity of the electric field.

The d.c./a.c. curves for the case of strong-weak anchoring are shown in Fig. 2. It is evident that the weak anchoring leads to nonlinearity in the curves.

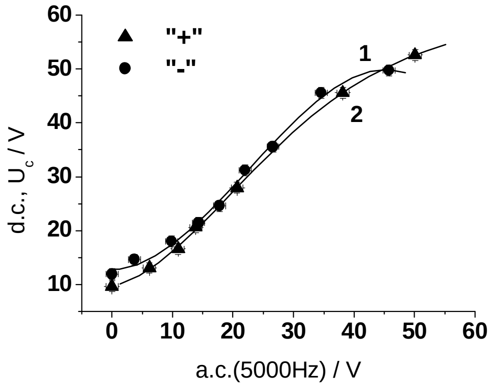

Fig. 2. The threshold voltage U_c in a strong-weak anchored nematic layer at the point of reversal of the polarity on the soap-treated plate, at room temperature.

4. Conclusions

The comparison of the experimental points and the theoretical curves clearly shows that the d.c./a.c. and *q*/d.c. curves are linear when the electric field is homogeneous, and nonlinear when it is inhomogeneous. Furthermore, the simultaneous application of low a.c. voltages (about 10-20 V) and a high d.c. voltage (40-50 V) considerably improves the arrangement of the domains and removes the defects (see Fig. 3).

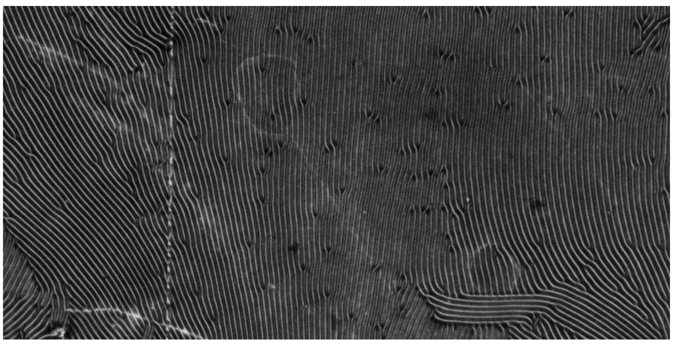

Fig. 3. Flexoelectric domains in a BMAOB nematic layer with a thickness of 8μm, under the joint action of 40 V d.c. and 20 V a.c., viewed with slightly uncrossed nicols. The long side of the photograph is 670 μm in size.

References

[1] L. K. Vistin', Kristallografiya **15**, 594 (1970).
[2] W. Greubel, U. Wolff, Appl. Phys. Lett. **19**, 213 (1971).
[3] Y. P. Bobylev, S.A. Pikin, Zh. Eksp. Teor. Fiz., **72**, 369 (Sov. Phys. JETP, **45**, 195 (1977).
[4] Y. P. Bobylev, V. G. Chigrinov, S. A. Pikin, J. Phys., Paris, Colloq., **40-C3**, C3-331 (1979).
[5] H. P. Hinov, I. Bivas, M. D. Mitov, K. Shoumarov, Y. Marinov, Liq. Cryst. **30**,1293 (2003).
[6] P-G. de Gennes, The Physics of Liquid Crystals, Clarendon Press, Oxford, U.K. (1974).
[7] R. B. Meyer, Phys. Rev. Lett. **22**, 918 (1969).