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TEMPORAL CHARACTERISTICS OF DC ELECTRIC FIELD INDUCED DEFORMATIONS OF FLEXOELECTRIC NEMATIC LAYERS

Dynamics of DC electric field induced deformations of flexoelectric nematic layers were studied numerically. The characteristic response times were calculated. It was found that the cooperative effect of flexoelectricity and of ionic space charge may affect the dynamics of the deformations even in the case of rigid anchoring.

Keywords: flexoelectric, nematic, director deformations.

1. INTRODUCTION

Nematic liquid crystals exhibit anisotropy of their all physical properties due to orientational order of elongated molecules which tend to align statistically along a preferred direction called the director, **n**. The mesogenic molecules have usually a permanent dipole moments which contribute to the dielectric anisotropy of the nematics. The asymmetric shape of the polar molecules gives rise to flexoelectricity of the nematics. The influence of external electric field on the nematic samples is determined by joined effects of dielectric anisotropy and flexoelectricity. The flexoelectric properties are described by two flexoelectric coefficients, e_{11} and e_{33}, associated with the splay and bend deformations respectively. They determine the relationship between the elastic deformation and the flexoelectric polarisation of the nematic, $\mathbf{P} = e_{11}\mathbf{n}(\nabla \cdot \mathbf{n}) - e_{33}\mathbf{n} \times (\nabla \times \mathbf{n})$ [1]. The linear coupling of the polarisation with the electric field leads to deformation, known as the converse flexoelectric effect. Flexoelectric properties are important for the interpretation of experimental results concerning the nematic layers subjected to electric fields [2-4]. The flexoelectricity of nematics has attracted a great deal of attention because several liquid crystal opto-electronic devices based on the flexoelectric effect was proposed [5-8].

Therefore the studies that yield us knowledge of the properties and behaviour of the flexoelectric nematic layers are basic in searching for potential applications. The static elastic deformations of flexoelectric nematic layers occurring under the action of external DC electric field were analyzed in our previous papers [9-14]. It was found that the ionic space charges influence the arising of deformations and the director distribution in the deformed states since they determine the electric field distribution. The dynamics of deformations arising in the flexoelectric nematic layers was also studied in our previous paper [15]. Our present work continues the numerical studies of these transient phenomena. We present results of calculations of the characteristic response times describing the rise as well as the decay of deformation after applying a voltage step and after switching off the voltage. They are defined in Figs. 1a and 1b for the arising and for the decay of deformations respectively. The delay time is defined as the time from the start of the applied voltage step to the instant when the maximum director orientation angle in the middle of the layer reaches 10% of its final value. The rise time is defined as the time duration for this angle to rise from 10 to 90% of its final value. The decay time is the time required for this angle to fall from 90 to 10% of its saturation value [16]. Our aim was to find the influence of flexoelectricity on these times.

We simulated layers containing nematic materials characterized by the negative dielectric anisotropy $\Delta\varepsilon$. The presence of ions was taken into account. The electric properties of the layer were described in terms of a weak electrolyte model. Mobility of cations was assumed to be one order of magnitude lower than that of anions. Quasi-blocking electrode contacts were assumed.

The system was described by a set of ten partial differential equations describing the torques acting on director, the transport of ions in the bulk and on the boundaries, and by the Poisson equation [9-15,20]. The main result is that the joined effect of the flexoelectric properties and of the presence of ions influence the arising of deformations even in the case of rigid anchoring. The decay time constant is not affected by the flexoelectric properties.

The paper is organized as follows. In the next section, we present the geometry and parameters of the flexoelectric nematic layers. In Section 3, the results of the simulations are presented and discussed.

2. GEOMETRY AND PARAMETERS

The parameters of the system under investigation were similar to those used in our previous papers devoted to DC field induced deformations [9-14]. The homeotropic nematic layers of thickness $d = 20$ μm and $d = 5$ μm, confined between two plates parallel to the *xy* plane of the coordinate system and placed at $z = \pm d/2$, were taken into account. The director **n** was parallel to the *xz* plane and its orientation was described by the angle $\vartheta(z,t)$, measured between **n** and the *z*-axis. The limiting plates played the role of electrodes. The lower electrode was earthed. For the case of deformation arising at the time $t = 0$, the voltage

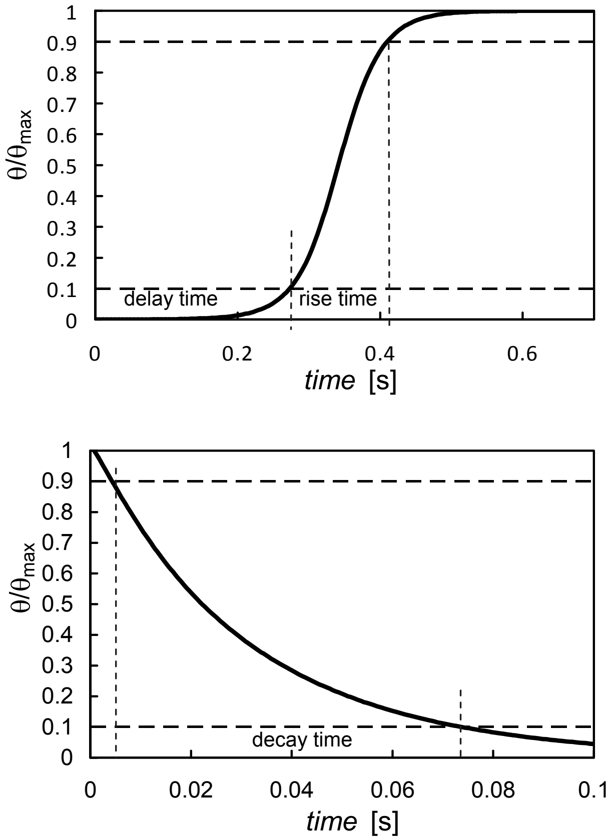

Fig. 1. Definitions of characteristic times which describe the dynamics of deformations.

step with amplitude $U = 5$ V was applied. For the case of decay, the zero voltage was applied to the state of saturated static deformation. The model substance was characterized by the elastic constants, $k_{11} = 6.2 \times 10^{-12}$ N and $k_{33} = 8.6 \times 10^{-12}$ N. A negative dielectric anisotropy, $\Delta\varepsilon = -0.7$, was adopted, and the value of $\varepsilon_\perp$ was 5.4. The flexoelectric properties were expressed by the sum of flexoelectric coefficients $e = e_{11} + e_{33}$ which was varied between –40 and

40 pC/m. The rheological properties of the nematic were expressed by rotational viscosity $\gamma_1 = 0.1093$ Ns/m^2 and by surface viscosity $\kappa = 2.6\times10^{-8}$ Ns/m (Ref. [17] and [18] respectively). The backflow effect was neglected. Rigid boundary anchoring was adopted.

The electrical properties of the layer were described in terms of a model which was used in our earlier papers [9-15]. The transport of ions under the action of the electric field was determined by their mobility coefficients. Typical values for the mobilities of liquid crystals were adopted. The mobility of the positive ions was assumed to be far less than that of the negative ions, $\mu_{\|}^{-} = 1.5\times10^{-9}$, $\mu_{\|}^{+} = 1.5\times10^{-10}$ m^{2}V^{-1}s^{-1}. Typical anisotropy of mobility, $\mu_{\|}^{\pm} / \mu_{\perp}^{\pm} = 1.5$ was adopted in both cases. The Einstein relation was assumed for the diffusion constants, $D_{\|,\perp}^{\pm} = (k_B T / q)\,\mu_{\|,\perp}^{\pm}$, where q denotes the absolute value of the ionic charge, k_B is the Boltzmann constant and T is absolute temperature. The weak electrolyte model was adopted where ion concentration in the thermodynamic equilibrium, N_0, was equal to 10^{18} m^{-3}, which is characteristic for pure liquid crystalline materials. Quasi-blocking electrodes were assumed, reflecting the fact that they are normally covered with insulating aligning films.

3. RESULTS AND DISCUSSION

The computations were performed for two thicknesses of the layers, $d = 20$ μm and $d = 5$ μm. The deformation were induced by the bias voltage $U = 5$ V in each case. Figures 2 and 3 present the dependence of characteristic times on the sum of flexoelectric coefficients. The role of thickness is evident.

For the thinner of the two layers, the variation of the times with e is weak. The strongest dependence occurs for the delay time. It obviously influences the total rise time which turns out to decrease with increasing flexoelectric coefficient e. The decay time remains practically unchanged. Symmetry of the plots with respect to $e = 0$ shows that the sign of e is of no importance.

In the case of the thicker layer, all the characteristic times are significantly larger. The role of the sign of flexoelectric coefficient is evident. The arising of deformations becomes very slow when the flexoelectric properties are determined by large negative flexoelectric coefficient. On the other hand, if the flexoelectricity is described by the positive e, then the delay time and the rise time are shorter than in the non-flexoelectric nematic. The influence of flexoelectricity on the decay time is negligible as in the previous case.

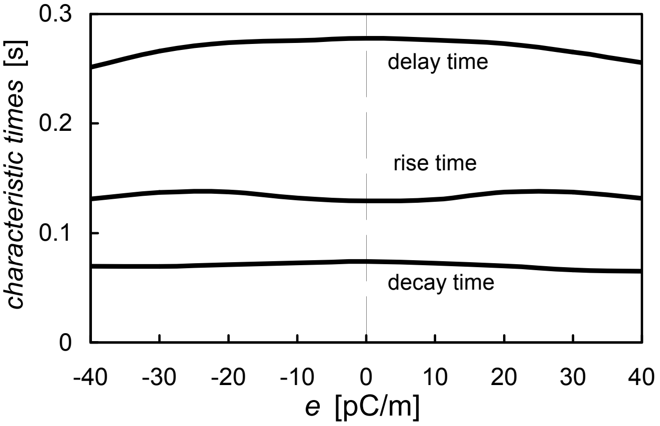

Fig. 2. Characteristic times for the layer of thickness 5 μm.

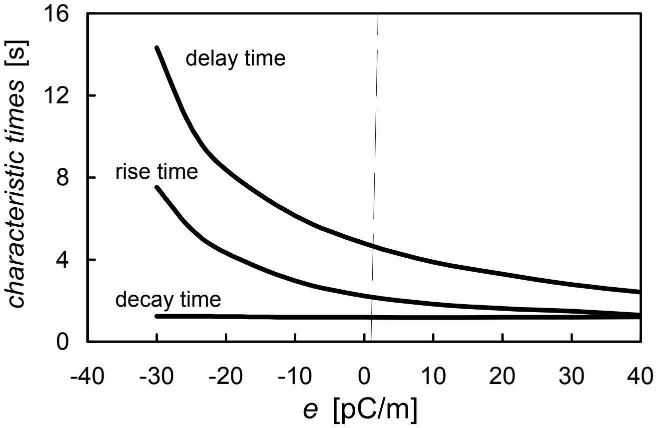

Fig. 3. Characteristic times for the layer of thickness 20 μm.

The effects mentioned above can be explained if the presence of ions is taken into account. The spatial distribution of ions reaches its equilibrium form during some very short time after application of voltage which is of the order of $d^2/\mu V$. In general, the ionic space charge determines the electric field distribution which interacts with the nematic by means of the destabilizing and stabilizing flexoelectric torques acting in the bulk and on the surfaces as well as by means of the destabilizing dielectric torque in the bulk [21]. In the present case, the rigid anchoring eliminates the role of the surface flexoelectric torques. The deformation is due to the bulk torques. They depend on the ionic space charge distribution which determines the distribution of the nonuniform electric field. The torques decide on the arising of deformation i.e. they determine the threshold voltage.

In the case of the thick layer, the threshold voltage depends significantly on the flexoelectric properties, [13], as shown in Fig. 4 where U_T is plotted as a function of e. In the case of the thin layer, the threshold is practically constant and equal to theoretical value $\pi\sqrt{k_{33}/\varepsilon_0\Delta\varepsilon}$. Comparison of Figs. 2, 3 and 4 shows the qualitative correlation between the times and the threshold. The delay time and the rise time shown in Fig. 3 are the longer, the closer to the threshold is the bias voltage. Weak dependence of the characteristic times on e presented in Fig. 2 is due to constant difference between U and U_T.

To summarize, our calculations showed that the cooperative effect of flexoelectricity and of ionic space charge affects the dynamics of the deformations of flexoelectric nematic layers even in the case of rigid boundary anchoring. The distributions of the ions has different form in the thick and in the thin layer. Therefore the influence of flexoelectricity on the dynamic behaviour depends on the thickness of the layer.

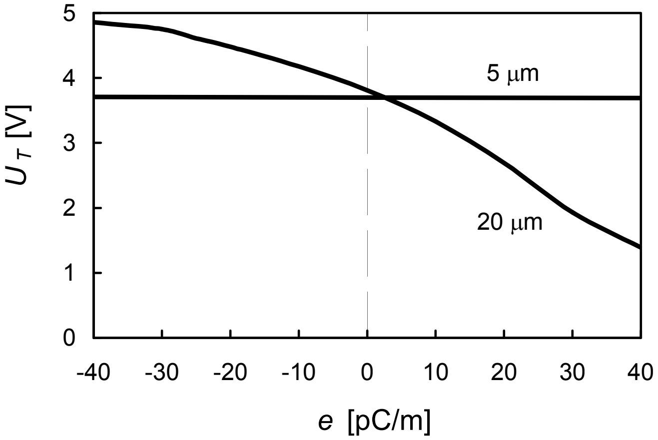

Fig. 4. Threshold voltage U_T as a function of the flexoelectric coefficient e. Thickness of the layer (in micrometers) is indicated at each curve

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CZASOWE CHARAKTERYSTYKI INDUKOWANYCH POLEM ELEKTRYCZNYM ODKSZTAŁCEŃ WARSTW NEMATYKA O WŁASNOŚCIACH FLEKSOELEKTRYCZNYCH

Streszczenie

Zbadano numerycznie dynamikę odkształceń wywołanych stałym polem elektrycznym w warstwach nematyków posiadających właściwości flekso-elektryczne. Obliczono charakterystyczne czasy odpowiedzi w funkcji sumy współczynników fleksoelektrycznych. Wyniki pokazują, że jednoczesne działanie momentów fleksoelektrycznych i jonowego ładunku przestrzennego wpływa na dynamikę odkształceń nawet w warunkach sztywnej orientacji powierzchniowej.