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REORIENTATION OF NEMATIC LIQUID CRYSTAL FILMS BY ALTERNATING AND STATIC FIELDS

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In the paper the electric field induced reorientation of a nematic liquid crystal film is investigated theoretically and experimentally. Both alternating and static fields are considered.

1. INTRODUCTION

IN THE last few years a number of papers have been published on the field-induced reorientation of a thin nematic liquid crystal (n.l.c.) layer, contained between two parallel glass plates and initially oriented perpendicular to the applied field ('Freedericks effect'). Both magnetic and electric field have been considered.[1–4] The usual theoretical approach to the problem is to calculate the minimum of the free energy, taking the field strength constant in the cell. However as liquid crystals behave rather as electrolytes than as dielectrics, thus in the case of electric field the real situation is, that the current is constant, and the field is determined by this condition. In the present communication we discuss some consequences following from this situation. Our discussion is restricted to n.l.c. possessing positive dielectric anisotropy.

Reorientation can be induced both by static and alternating field. In the case of alternating field we assume the frequency to be high enough that the alignment of the molecules cannot follow the alternation of the field (typically > 100 Hz) but low enough, that the polarization can follow it (typically $< 10^6$ Hz). For alternating fields the term 'current' means the sum of conductive and displacement current. For low frequencies, $\omega \ll \sigma/\epsilon$, the conductive part of the current is important, while for high frequencies, $\omega \gg \sigma/\epsilon$, the displacement current is the dominant. From this we conclude that the process of reorientation depends on the frequency of the applied field. In the paper a calculation is presented, which provides quantitative results on this frequency-dependence. The considerations are illustrated by experimental results, obtained by the optical birefringence technique.[3,4]

In the case of static fields the current must flow through the electrodes, so electrode processes become important. Double layers are formed at the electrodes, which decrease the field in the cell, so a higher applied voltage is needed to reorientate the layer as in case of alternating fields. (The development of the double layers takes several seconds, so they can be completely neglected for alternating fields.) This fact is demonstrated as well experimentally.

2. THEORY FOR ALTERNATING FIELDS

For alternating fields the connection between the current, i.e. displacement and the electric field can be assumed to be resp:

$$\mathbf{j} = \sigma_\perp \mathbf{E} + \sigma_a(\mathbf{nE})\mathbf{n}; \quad \mathbf{D} = \epsilon_\perp \mathbf{E} + \epsilon_a(\mathbf{nE})\mathbf{n}$$

where $\sigma_\perp$, σ_a i.e. $\epsilon_\perp$, ϵ_a are the perpendicular component and the anisotropy of the conductivity i.e. dielectric tensor, $\mathbf{n}$ is the director. From the continuity of the total current, $\mathbf{j} + i\omega\mathbf{D}$, we obtain

$$E_x = E_y = 0; \quad E_z = E_0 \frac{1}{1 + \beta \sin^2 \nu} \qquad (1)$$

with

$$\beta = \frac{\sigma_a + i\omega\epsilon_a}{\sigma_\perp + i\omega\epsilon_\perp}$$

where ν is the angle between the director and the direction of the alignment in the fieldless state. ν is a function of the distance from the wall, z, and is determined by the balance between the torque, produced by the field in the material

$$M_E = \alpha_a E_z E_z^* \sin \nu \cos \nu \tag{2}$$

and the torque arising from the deformation of the uniform alignment

$$M_D = (K_{11} \cos^2 \nu + K_{33} \sin^2 \nu) \frac{d^2\nu}{dz^2} + (K_{33} - K_{11}) \sin \nu \cos \nu \left(\frac{d\nu}{dz}\right)^2 \tag{3}$$

K_{11} and K_{33} are elastic constants.

Assuming, that the alignment is undisturbed at the walls when field is applied, i.e. $\nu(0) = \nu(L) = 0$, we obtain

$$z(\nu) = \int_0^\nu \left\{ \frac{K_{11} \cos^2 \nu + K_{33} \sin^2 \nu}{F(\nu_m) - F(\nu)} \right\}^{1/2} d\nu \tag{4}$$

with

$$F(\nu) = 2 \int_0^\nu M_E \, d\nu; \qquad \nu_m = \nu(L/2)$$

The relation between ν_m and the applied voltage, V, is fixed by the condition

$$V = \int_0^L E_z \, dz \tag{5}$$

(It is assumed that the function $\nu(z)$ has only one extremum in the cell. There exists solutions with more than one extremum, however the energies belonging to these solution are higher than in the case discussed).

From this solution a threshold voltage, $V_{th} = \pi \sqrt{(K_{11}/\alpha_a)}$ is obtained, at which the deformation of the liquid crystal layer starts. The threshold is independent of β, thus of the frequency of the applied voltage. However, the deformation above the threshold depends on β, i.e. on the frequency.

In the birefringence measurements a laser beam is let through the cell, and the phase difference between its components polarized perpendicularly and parallel to the initial direction of the molecules is measured. The phase difference is

$$\Delta\phi = \frac{2\pi}{\lambda} \int_0^L \Delta n \, dz \tag{6}$$

with

$$\Delta n = \frac{n_e}{\sqrt{1 + \frac{n_e^2 - n_o^2}{n_o^2} \sin^2 \nu}} - n_o$$

where n_e and n_o are the extraordinary and ordinary refractive indexes, respectively.

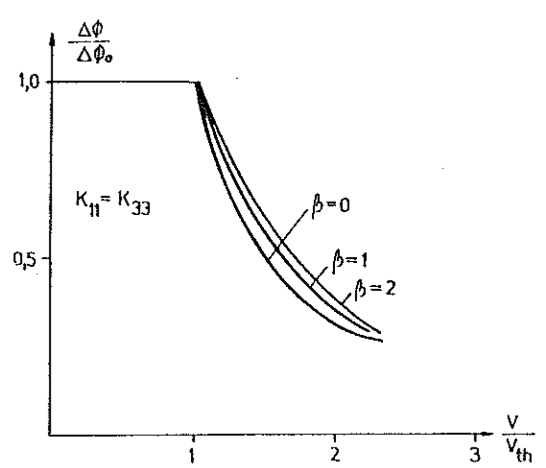

FIG. 1. The phase difference as a function of the applied voltage. $K_{11} = K_{33}$, $n_e - n_o \ll 1$. $\Delta\phi_0$ is the phase difference belonging to the indisturbed cell.

With the help of equations (4–6) $\Delta\phi$ can be computed as a function of V. In Fig. 1 $\Delta\phi$ is presented as a function of V, in the case when $n_e - n_o \ll 1$, $K_{11} = K_{33}$ and β is real. In the general case the slope of the $\Delta\phi(V)$ curves at the threshold is

$$\frac{\partial \Delta\phi/\Delta\phi_0}{\partial V/V_{th}} = -\frac{n_e(n_e + n_o)}{n_o^2} \frac{1}{\mathrm{Re}\,\beta + K_{33}/K_{11}} \tag{7}$$

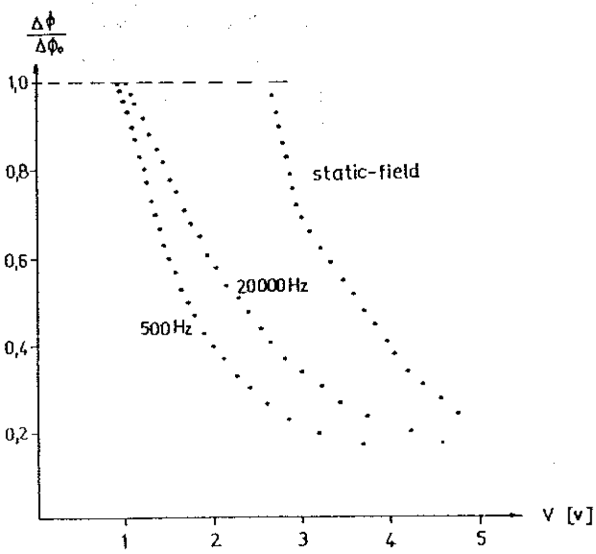

FIG. 2. Experimental results on PEBAB. $T = 115°C$, cell thickness 30 μm.

3. EXPERIMENTAL RESULTS

In Fig. 2 experimental curves, measured on PEBAB (n4-ethoxybenzilidene 4-amino-benzonitride) are presented. On our material we found at $T = 115°C$, $\sigma_a/\sigma_\perp = 0.85$, $\epsilon_a/\epsilon_\perp = 1.83$.[5] This means that β is larger for high frequencies than for low frequencies. We found in accordance with equation (7), that as the frequency was increased, the slope of the curves at the threshold decreased (in absolute value), meanwhile the threshold remained unchanged. Quantitative analysis of the results will be published elsewhere.

In Fig. 2 a result, obtained for static field is displayed as well. The static curve can be approximately regarded as a shifted low-frequency curve, the shift being ~1.5 V. This shift is due to the double layers, formed at the electrodes. However, the space charge distribution may be rather complicated in the cell for static fields,[6] hence this simple picture has to be refined to achieve accurate agreement between theory and experiments.

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В статье описывается теория переориентации тонкого слоя нематического кристалла во внешнем постоянном и переменном полях. В работе даются и экспериментальные результаты.