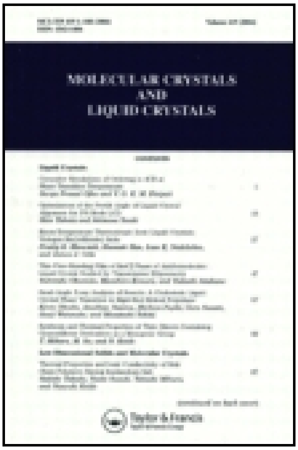

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Hysteresis of Light Induced Fréedericks Transition Due to the Static Electric Field

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It is shown that when a quasistatic electric field (not inducing the Fréedericks transition) is applied to a cell with a nematic liquid crystal (NLC), a hysteresis can arise in the dependence of the NLC director reorientation on the intensity. The critical tension of the static field inducing hysteresis is calculated.

INTRODUCTION

The theory of the light induced Fréedericks transition (LIFT) in nematic liquid crystals (NLC) predicts a hysteresis of the dependence of the director reorientation on the intensity of the light wave.[1] This effect takes place for some strongly anisotropic NLC, for which the parameter

$$B_0 = \frac{1}{4}\left(1 - \frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel} - \frac{K_3 - K_1}{K_3}\right) \tag{1}$$

is negative. The usual denotions are used in (1): $\epsilon_a = \epsilon_\parallel - \epsilon_\perp$ is the anisotropy of the NLC dielectric constant at light frequencies, K_i are the Frank constants. The condition $B_0 < 0$ is satisfied for PAA; as an example $\mathbf{B}_0 = -0.03$ at $T = 125°C$. The effects of the light induced reorientation of the director have been investigated in some papers under conditions in which a quasistatic electric field is applied additionally to the cell.[2-4]

The purpose of the present paper is to show that the application of a quasistatic electric field can induce a hysteresis of the LIFT even in cells of NLC with $B_0 > 0$.

RESULTS AND DISCUSSION

When a linearly polarized light wave is incident normally (along the z-axis) to a cell of homeotropically aligned NLC, and the beam size is assumed to be larger than the NLC layer thickness, one can consider that the director distortions induced by the light field of an intensity exceeding some threshold value are in the polarization plane of the wave.

Assume also that the anisotropy of the low-frequency dielectric constant $\epsilon_a^0 = \epsilon_{\parallel}^0 - \epsilon_{\perp}^0$ of the NLC is positive. The quasistatic electric field applied parallel to the director cannot then bring about the director reorientation. To investigate this field influence upon the LIFT, let us write down the equation for the director reorientation angle θ.

In the presence of the light field and the quasistatic field, that equation can be obtained in the form[1,4].

$$\left(K_1\sin^2\theta + K_3\cos^2\theta\right)\frac{d^2\theta}{dz^2} - (K_3 - K_1)\sin\theta\cos\theta\left(\frac{d\theta}{dz}\right)^2$$

$$+\left(\frac{\pi}{L}\right)^2\frac{P.}{P_{Fr}}\frac{K_3\sin\theta\cos\theta}{\left(\epsilon_\perp + \epsilon_a\cos^2\theta\right)^{3/2}} - \frac{\epsilon_a^0|D_z|^2\sin\theta\cos\theta}{4\pi\left(\epsilon_\perp^0 + \epsilon_a^0\cos^2\theta\right)^2} = 0 \quad (2)$$

where L is the cell thickness, P is the incident wave power density, D_z is the z-component of the induction of the quasistatic electric field, which is constant in the geometry under consideration due to the condition $\operatorname{div}\mathbf{D} = 0$; $P_{Fr} = (c\epsilon_{\parallel}K_3/\epsilon_a\sqrt{\epsilon_\perp})(\pi/L)^2$ is the LIFT threshold power density in the absence of the quasistatic field. Linearization of eq. (2) with account of $\theta(z) \approx \theta_m\sin(\pi z/L)$ determines the power density of the LIFT switching on in the presence of the quasistatic field

$$P_{th} = P_{Fr}(1 + \xi_E) \quad (3)$$

where $\xi_E = \epsilon_a^0U^2/(4\pi^3K_3)$, U is the potential difference between the NLC cell plates.

The determination of the director above-threshold structure at

LIFT requires consideration of eq. (2) with account of the nonlinearity in θ terms. Taking into account the terms $\sim\theta^3$ and using the procedure similar to that in ref 1, we get

$$\theta_m^2 = \frac{1+\xi_E}{2B(\xi_E)} \frac{P-P_{th}}{P_{th}}$$
$$B(\xi_E) = \frac{1}{4}\left[1 - \frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel} - \frac{K_3-K_1}{K_3} - \left(\frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel} - \frac{\epsilon_a^0}{\epsilon_\parallel^0}\right)\xi_E\right] \tag{4}$$

At $\xi_E = 0$, eq. (4) gives the result in ref. 1, where it is shown, that for $B(\xi_E) \leqslant 0$, the equation of the form (4) is not valid and a more accurate solution of the nonlinear eq. (2) is required. The dependence of θ_m^2 on P is more complicated in this case. Particularly, the intensities of the LIFT switching on and switching off turn out not to be coincident, and this leads to the hysteresis in the dependence of θ_m^2 on P.

Consider the case $B(\xi_E = 0) > 0$. Then, as follows from (4), if

$$G \equiv \frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel} - \frac{\epsilon_a^0}{\epsilon_\parallel^0} > 0 \tag{5}$$

the quasistatic field application leads to the change of the quantity $B(\xi_E)$, i.e., for the same excess of power density P over the threshold P_{th}, the electric field increases the director reorientation angle. There is a critical value of the tension of the quasistatic field which changes the sign of $B(\xi_E)$. As was mentioned, this corresponds to the hysteresis formation in the LIFT. The corresponding critical potential difference is equal to

$$U_c = \left[\frac{16\pi^3 K_3}{\epsilon_a^0}\frac{B(\xi_E = 0)}{G}\right]^{1/2} \tag{6}$$

If B $(\xi_E = 0) < 0$, the quasistatic field strengthens the hysteresis (at $G > 0$) or reduces it (at $G < 0$) right up to disappearance. The determination of the LIFT switching off intensity requires us to integrate the complicated equation (2).

It can be shown easily that the hysteresis of the LIFT can be induced also by a static magnetic field applied along the director.

Solving an equation analogous to eq. (2), we obtain in this case

$$\theta_m^2 = \frac{1+\xi_H}{2B(\xi_H)}, \qquad P_{\text{th}} = P_{Fr}(1+\xi_H)$$
$$B(\xi_H) = \frac{1}{4}\left(1 - \frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel} - \frac{K_3 - K_1}{K_3} - \frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel}\xi_H\right) \tag{7}$$

where $\xi_H = \chi_a H^2 L^2/(\pi^2 K_3)$, χ_a is the diamagnetic anisotropy. From the eq. (7) we get the tension of the critical field

$$H_c = \left[\frac{4}{9}\frac{\epsilon_\parallel K_3}{\epsilon_a \chi_a}\left(\frac{\pi}{L}\right)^2\left(1 - \frac{9}{4}\frac{\epsilon_a}{\epsilon_\parallel} - \frac{K_3 - K_1}{K_3}\right)\right]^{1/2} \tag{8}$$

Thus the application of quasistatic fields can induce a hysteresis of the LIFT.

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