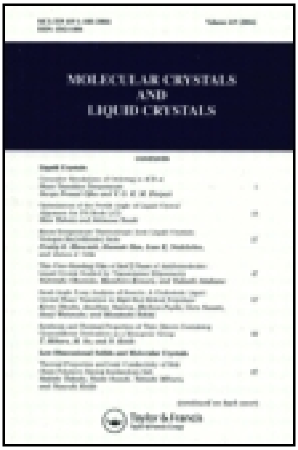

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A. Nych [a] , M. Voronin [a] , V. Pergamenshchik [a] , Yu. Kolomzarov [b] , V. Sorokin [b] & V. Nazarenko [b]

[a] Institute of Physics, 46 Nauki ave., Kyiv, 03039, Ukraine

[b] Institute of Semiconductor Physics, 45 Nauki ave., Kyiv, 03028, Ukraine

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MEASUREMENT OF THE TWIST ELASTIC CONSTANT BY PHASE RETARDATION TECHNIQUE

A. Nych, M. Voronin and V. Pergamenshchik
Institute of Physics, 46 Nauki ave., Kyiv, 03039, Ukraine

*Yu. Kolomzarov, V. Sorokin and V. Nazarenko**
Institute of Semiconductor Physics, 45 Nauki ave., Kyiv, 03028, Ukraine

We have extended the experimental approach, used by Yu. A. Nastyshyn et al. [J. Appl. Phys. **86***, 4199 (1999)] for measuring polar anchoring strength, to measure the twist elastic constant in nematic liquid crystal. The method implies measurements of phase retardation changes in liquid crystal under the action of magnetic field. The obtained experimental data were fitted with the predictions of elastic theory. We found that the value of the measured elastic constant, K_{22}, is in good agreement with those described in literature.*

Keywords: liquid crystal; elastic constant; phase retardation

INTRODUCTION

The elastic constants of nematic liquid crystals have attracted considerable interest for many years and for numerous researchers [1–12]. This interest largely comes from the fact that elastic constants appreciably influence important display properties such as the threshold voltage, steepness of the electro-optical characteristic and so on. The demand to fabricate low power consumption, wide operation temperature range, high contrast and fast switching time LCDs provides the rationale for the precise knowledge of elastic constant values as well as their temperature dependence. The reason why many reports are still concerned with the elastic constants is that the measurements are far from to be trivial.

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*Corresponding author. E-mail: vnazaren@iop.kiev.ua

The elastic constants of nematic liquid crystals are usually measured by the using Freedericksz transition induced by magnetic or electric field [1–6]. The experiments concern the investigation of direct measurement of the elastic torque exerted from a nematic sample on a glass plate were performed in [7,10]. Other methods have been also proposed in [9] and in [11]. However, the most reliable values of elastic constants have been obtained from measurement of the Freedericksz transition in thin nematic layer. In most of these experiments the magnetic or electric field is applied perpendicular to the director. The director distortion occurs when the field exceeds a threshold value, H_C. By assuming the strong anchoring of the director at the interface of the nematic layer one obtains $H_C = \pi/d\sqrt{K_{ii}/\chi_a}$, where d is the thickness of layer, χ_a is anisotropy of magnetic susceptibility and K_{ii} is an elastic constant ($i = 1$– splay, $i = 2$ – twist, $i = 3$ – bend). The accuracy of the described method strongly depends on the director orientation at the interface. Even small deviation of the director results in sufficient shift of the threshold field.

In the current paper we suggest an experimental technique to measure the twist elastic constant from the dependence of phase retardation of liquid crystal layer on the applied magnetic field. For a certain range of directions of the applied magnetic field the phase retardation demonstrates changes monotonically with the magnetic induction. K_{22} is determined from a simple fit of experimental curve.

EXPERIMENT

Experiments were performed for the cells with alignment induced by coating of two glass substrates with the rubbed polyimide layer. The polyimide we used, LARC-CP1, provides almost planar orientation, the deviation of the angle between the substrate and director is less than 1° [13]. The cells were filled with the nematic liquid crystal 5CB, purchased from EM Industries and used without any additional purification, with the parameters as following: extraordinary refractive index $n_e = 1.708$ [1], ordinary refractive index $n_o = 1.530$ [1], (both at wavelength $\lambda = 632.8\,\mathrm{nm}$), anisotropy of magnetic susceptibility $\chi_a = 113.5 \times 10^{-12}\ \mathrm{kg}^{-1}\mathrm{m}^3$ [5]. The optical phase retardation of the liquid crystal cell was determined by the Senarmont technique (see, for example [14,15]). Schematically this setup is shown on Fig. 1. The light source was He-Ne laser ($\lambda = 633\,\mathrm{nm}$). The linear polarized light entering the sample emerges elliptically polarized. Setting the optical axis of the quarter-wave plate parallel to the polarizer transforms the elliptically polarized light passed through the cell into linear polarized light. The measurement of the azimuth of this linear polarized light using the analyzer allows for determination of the phase retardation of the sample.

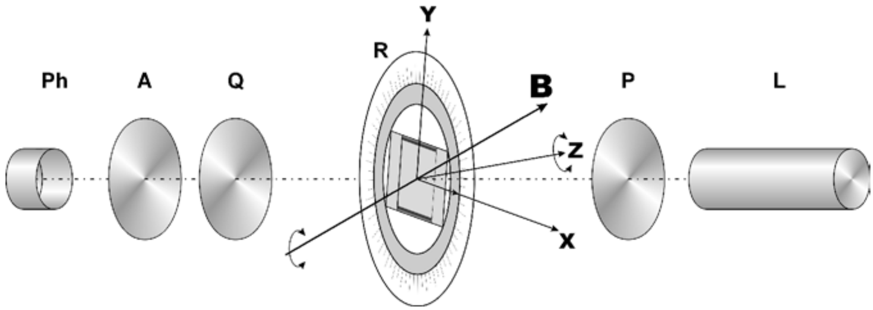

FIGURE 1 Experimental setup: L-laser, P-polarizer, R-rotating sample holder and LC cell, Q-quarter-lambda plate, A-Analyzer, Ph-Photodetector. The rotating sample holder allow the LC cell to be rotated around magnetic field direction **B** and around perpendicular to the cell surface direction (**Z**-axis). Rotation around the former axis changes the incidence angle of the laser beam β, while the angle α remains the same. Rotation around the **Z**-axis changes only the angle α. During these rotations magnetic field direction always lies in the plane of the cell.

RESULTS AND DISCUSSION

A common nematic liquid crystal is uniaxial crystal, meaning that one crystal axis is different from the other two. The single crystal axis that is unique is often called the "extraordinary" axis and its associated refractive index is labeled n_e, while the other two axes are "ordinary" axes with index n_o [14]. The amount of phase retardation that monochromatic wave acquires from traveling trough a nematic liquid crystal is related to a refractive index, n, wavelength, λ, and the path length inside the crystal, L, as

$$\Phi = \frac{2\pi}{\lambda} nL \tag{1}$$

An input beam that is normally incident on the liquid crystal layer will be resolved into ordinary and extraordinary axis components, each with a different refractive index. The beam that emerges has a phase delay difference or retardation between the axes. Applied magnetic field results in reorientation of liquid crystal molecules along the direction of the field. Since the distortion starts in the middle of the cell the resultant structure consists of twist deformation with maximum amplitude in the center of the cell and the director coincides this rubbing directions at the interfaces. However, for normal incidence the polarization of light transmitted through the liquid crystal layer is not distinguishing from that transmitted through twisted nematic layer. There is no detectable retardation, since the polarization of light follows director deformation so the polarization of emerging

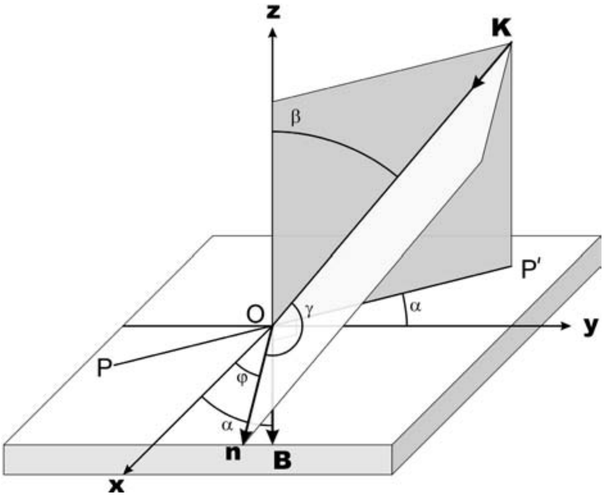

FIGURE 2 Illustration for theoretical calculations. The **X**-axis lies along the rubbing direction of the sample. Angle φ is the angle between nematic director **n** and **X**-axis (director deviation from rubbing direction). Angle α is the angle between magnetic field **B** and **X**-axis. PP′ is a line in **XOY** plane, perpendicular to the magnetic field direction **B**. Angle β is an incidence angle of laser beam. Note that during rotation around magnetic field direction only the β angle is changed and direction of light propagation **K** always lies in ZPP' plane. Angle γ is the angle between nematic director **n** and propagation direction of laser beam.

light always corresponds to the director orientation at the interface. The light is “ignorant” of the deformation inside liquid crystal layer. But, when the cell is tilted toward or away from the light beam, the amount of retardation depends on the degree of tilt and has an angular sensitivity to director twist.

Let us consider a homogeneously aligned nematic layer placed in magnetic field as it shown in Fig. 2. Input light, that is linearly polarized, makes a certain angle β with the cell. In the initial position the rubbing direction of the nematic cell was aligned along magnetic field. Then cell was rotated on an angle α around the normal to the cell in so manner that magnetic field induce only twist deformation of the director. In this geometry the effective extraordinary refractive index, n_{eff}, of the LC becomes

$$n_{eff} = \frac{n_e \cdot n_o}{\sqrt{n_o^2 \cdot \sin^2\gamma + n_e^2 \cdot \cos^2\gamma}}, \qquad (2)$$

where γ is the angle between the director and input light beam. γ can be determined from defined angles β and α as follow $\cos\gamma = -\sin\beta\cdot$

$\sin(\alpha - \varphi)$, where φ is the angle between director and rubbing direction. The angular dependent phase retardation of the liquid crystal layer is expressed as

$$\Phi = \frac{2\pi}{\lambda} \int_{-d/2}^{d/2} \Delta n_{eff} \mathrm{d}z, \tag{3}$$

where d is the thickness of liquid crystal layer and

$$\Delta n_{eff} = \frac{n_i}{\sqrt{n_i^2 - \sin^2 \beta}} \left(\frac{n_e \cdot n_o}{\sqrt{n_o^2 \cdot \sin^2 \gamma + n_e^2 \cdot \cos^2 \gamma}} - n_o \right). \tag{4}$$

The first factor, $n_i/\sqrt{n_i^2 - \sin^2 \beta}$, in Eq. (4) originates from the increased optical path length and it takes into account a light refraction at the liquid crystal/glass interface. Just after passing an isotropic glass layer, ordinary and extraordinary beams will possess a different refraction indexes and thus they will propagate separately. To simplify our calculations we assume that both beams refract together with index of refraction, that equals to isotropic refractive index of the nematic liquid crystal, $n_i = (2n_o + n_e)/3$.

In the presence of the magnetic field, the Frank free energy density corresponding to the twist deformation is given by

$$F_d = \frac{1}{2} K_{22} \left(\frac{\partial \varphi}{\partial z} \right)^2 - \frac{1}{2} \frac{\chi_a}{\mu_0} (\mathbf{n} \cdot \mathbf{B})^2 \tag{5}$$

where K_{22} is the twist elastic constant, χ_a is the anisotropy of the magnetic susceptibility, $\mathbf{B}$ is the magnetic field induction [16]. The magnetic field is taken to be small so that the energetic cost of surface director deviations can be neglected. In our geometry (see Fig. 2) we assume that angle α between $\mathbf{B}$ and rubbing direction, and thus the angle between nematic director $\mathbf{n}$ and $\mathbf{B}$, is small. In this case Eq. (5) can be written as follow:

$$F_d = \frac{1}{2} K_{22} \left(\frac{\partial \varphi}{\partial z} \right)^2 - \frac{1}{2} \frac{\chi_a B^2}{\mu_0} \left(1 - (\alpha - \varphi)^2 \right), \tag{6}$$

where α is the angle between magnetic field $\mathbf{B}$ and rubbing direction ($\mathbf{X}$-axis) and angle φ is the angle between nematic director $\mathbf{n}$ and rubbing direction. Solving the Eq. (6) one can obtain the relationship between the angle of director deviation and the applied magnetic field as a function of $\mathbf{z}$-coordinate:

$$\varphi(z, B) = \alpha \left(1 - \frac{\cosh(q(B)z)}{\cosh\left(q(B)\frac{d}{2}\right)} \right), \tag{6}$$

where $q^2(B) = \frac{\chi_a B^2}{\mu_0 K_{22}}$.

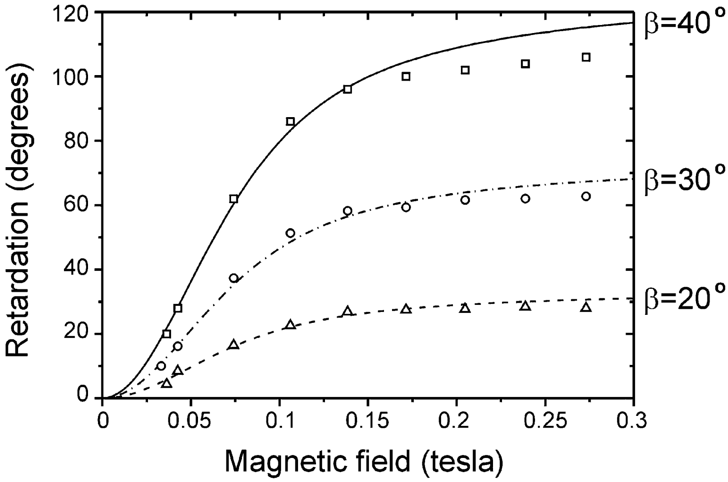

FIGURE 3 Phase retardation as a function of the magnetic field. Lines represent theoretical fit for $K_{22} = 3.13 \cdot 10^{-12}$ N of corresponding experimental data (squares, circles and triangles). The angle between magnetic field and rubbing direction $\alpha = 20°$ and the incident angle of laser beam for each data set is shown on the plot. Other parameters are as follows: $n_e = 1.708$, $n_o = 1.530$, $d = 50\,\mu$m, $\chi_a = 113.5 \times 10^{-12}\,\mathrm{kg}^{-1}\,\mathrm{m}^3$, $\lambda = 632.8$ nm.

Experimental data on the field induced change of the phase retardation, $\Delta\Phi(B) = \Phi|_B - \Phi|_{B=0}$, allows one to compare these experimental data with the prediction of the elastic theory, Eq. (6). The both experimental and theoretically calculated dependencies $\Delta\Phi(B)$ are shown in Fig. 3, where the circles correspond to experimental values and solid lines represent calculated retardation. Within the all area of experimental data the theoretical fit is good. As an adjustable parameter to numerically solve the Eq. (3) and (6) we used the elastic constant K_{22}. The best fit of experimental data provides us with the value of K_{22}. The measurements were carried out at the temperature 25°C.

Thus, we obtained the following value of the twist elastic constant $K_{22} = 3.13 \cdot 10^{-12}$ N. The estimated value of K_{22} elastic constant is approximately 10% larger from those reported in [4] and is about the same order of magnitude with those reported in [9]. However, the choice of the χ_a value may influence the value of the twist elastic constant measured in the present experiment.

Finally we remark that we found good agreement of K_{22} with the values reported in literature [4,9]. The developed approach can be very useful to measure the twist elastic constant in pretransitional phenomena like nematic to cholesteric transition or in twisted nematic. Further experimental and theoretical work is at present being carried out in order to make a comparison on the values of K_{22} obtained for uniformly aligned nematic layer and for twisted nematic layer.

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