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Optical Response of Nematic Droplets in a Polymer Matrix to a Strong Pulsed Magnetic Field

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Abstract—A change in the optical transmission of an ordered single-layer ensemble of nematic liquid crystal (NLC) droplets of 4-*n*-pentyl-4'-cyanobiphenyl (5CB) in a poly(vinyl butyral) (PVB) matrix in response to a magnetic field pulse with an amplitude of $H = 9 \times 10^6$ A/m was observed. Since the leading pulse front duration (τ_{onH} = 5 ms) significantly exceeded the theoretically calculated NLC response time (τ_{onLC} = 0.8 ms), the dynamics of transformations of the NLC director orientation and the optical response were analogous to those in the case of a stationary or slowly varying magnetic field. In contrast, the field decay time (τ_{offH} = 25 ms) was much shorter than the NLC relaxation time (τ_{offLC} = 300 ms) and, hence, the trailing front of the optical response was not influenced by the oscillatory character of the magnetic field decay during capacitor discharge via an *RL* chain.

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At present, the properties of composite films based on polymer-dispersed nematic liquid crystals (PDNLC) are most exhaustively studied with respect to the possibility of controlling their optical properties by an external electric field. In particular, the electrooptical effect in liquid-crystalline composite films underlies their use in devices with the field-switched optical scattering [1]. Nevertheless, there are some features of PDNLC that restrict the possibilities of using the electrooptical effect in these materials in basic research. These difficulties are primarily related to the fact that PDNLC are anisotropic media with inhomogeneous dielectric properties. Calculations of the field distribution in such a composite film are especially complicated in dynamic cases, where the dielectric properties of NLC droplets vary both as a result of the intrinsic transformations of the NLC director orientation during the control field pulse and due to the mobility of unavoidably present ion carriers [2]. The use of a magnetic field eliminates both the problem of ion-induced repolarization of NLC droplets and the need in making allowance for the inhomogeneity of a composite structure, since the magnetic susceptibilities of components are close. However, the magnetooptical investigations are technically more difficult in view of the high values (reaching several tens kOe) of the threshold field for the Freédérickcz transition in a closed geometry of a polymer capsule [3, 4].

This Letter presents the results of an investigation of the dynamics of the optical response of PDNLC to a magnetic field pulse with amplitude significantly exceeding the threshold field.

The experiments were performed with a sample comprising a polymer film containing dispersed NLC in the form of ellipsoidal inclusions. The film was prepared using the method of phase separation in a mixture of 4-*n*-pentyl-4'-cyanobiphenyl (5CB) and poly(vinyl butyral) (PVB) upon the evaporation of a common solvent (ethyl alcohol) [1]. The percentage ratio of components and the solvent evaporation rate were varied so as to obtain a composite structure with the most homogeneous ensemble of NLC droplets with respect to size and with their single-layer arrangement in the film. Figure 1 shows the top view of a fragment of this film as observed in crossed polarizers of a microscope. The orientational structure of NLC in a capsule (droplet) is a configuration characterized by two poles that represent point disclinations at the capsule boundary. The axes of these bipolar droplets, which pass through the point defects, are lying predominantly in the film plane and possessing arbitrary azimuthal orientations. The observed pattern is typical of an ensemble of oblate capsules, the minimum transverse size ($2c$) of which is comparable with the film thickness. The characteristic aspect ratio of these dispersed structures is $l = a/c \approx 1.4$ [3].

The optical transmission of the PENLC sample was measured using the normally incident beam of a He–Ne laser with a wavelength of 633 nm. The incident radiation was diaphragmed at the photodetector entrance so that only a directly propagating beam frac-

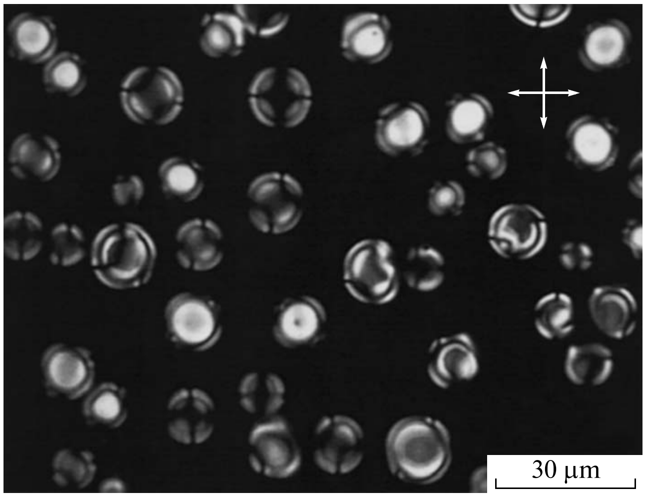

Fig. 1. Micrograph of a fragment of the PVB film with dispersed NLC (5CB) droplets. Arrows indicate the orientations of crossed polarizers of a microscope.

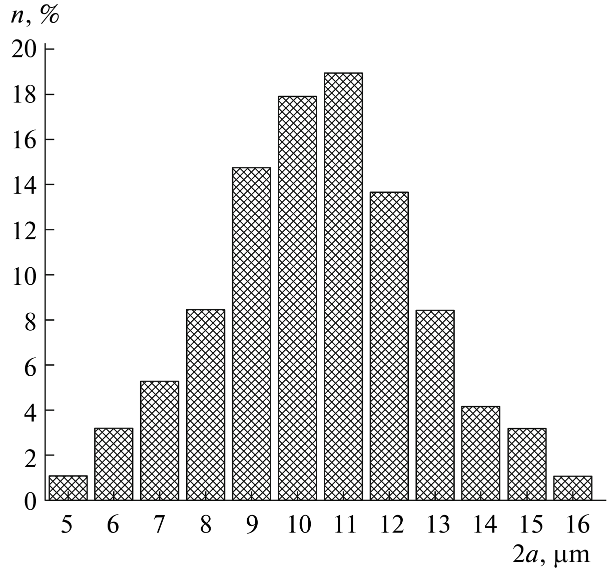

Fig. 2. Histogram of the distribution of 5CB droplets with respect to their size $2a$ (in a sample of $n = 400$).

tion would be detected. The scanning beam probed a rather large number (n) of scattering objects (droplets). In the case under consideration, we have $n \cong 600$ that admits the application of statistical analysis to studying the Freédericksz transition in the PENLC. Figure 2 presents a histogram of the distribution of droplets with respect to their size ($2a$) in the statistical ensemble (probed film sample) The results of these measurements were used to calculate the average droplet size, which proved to be $\langle 2a \rangle = 10.5$ μm.

The optical response to a constant magnetic field was studied using a method described elsewhere [3]. An increase in the sample transmission during slow variation of the magnetic field exhibited a threshold character. The threshold magnetic field was found to be $H_0 \approx 8.8 \times 10^5$ A/m.

The dynamics of the optical response was studied using a pulsed setup with a consumed energy of 60 kJ. The pulsed magnetic field was generated by a capacitor discharge current passing through a solenoid. The sample was placed in a temperature-controlled cell inside the solenoid and oriented so that the film plane was perpendicular to the magnetic field. The field in the solenoid was measured by the induction technique [5] using a copper wire coil wound on a hollow nonmagnetic frame surrounding the sample. The voltage U induced by the variable magnetic field was proportional to the number of turns N, their area S, and the speed of field variation with the time: $U(t) = NS(dH/dt)$. The field magnitude H was determined with the aid of an integrator whose time constant (τ_i = 300 ms) was chosen to be much greater than the discharge circuit time constant $\tau_d \cong 30$ ms (determined by the discharge bank capacitance and the solenoid inductance), on the one hand, and sufficiently small to ensure that the signal amplitude $U(t)$ would be significantly large and could be reliable measured, on the other hand.

Figure 3 (curve *1*) shows the time series of a magnetic field pulse measured during the discharge of the capacitor bank in comparison to the optical response (curve *2*). The field pulse has a negative half-wave, which is typical of an oscillatory discharge of a capacitor through an RL chain [6]. The time of the magnetic field rising to the maximum level ($H = 9 \times 10^6$ A/m) is (τ_{onH} = 5 ms). As can be seen, the time of the NLC response to the field action almost coincides with this value. With neglect of a weak contribution of

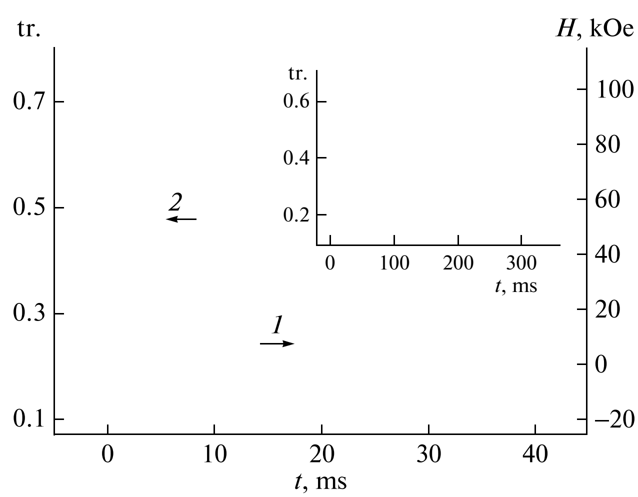

Fig. 3. Time series of the (*1*) magnetic field pulse and (*2*) PENLC optical response. The inset shows the same optical response plotted on a greater time scale.

higher harmonics to the oscillatory discharge of the capacitor through the *RL* chain [6], the magnetic field decays within a time of τ_{offH} = 25 ms. The compete NLC relaxation time amounts to τ_{offLC} = 300 ms (see the inset to Fig. 3).

In most cases, the 5CB–PVB composition is characterized by strong planar interaction at the interface, the fixation of polar disclinations, and an S-shaped profile of the NLC director deformation during the Freéderickcz transition [3]. The problem of determining dynamic parameters in this system cannot be solved analytically and requires using numerical techniques. For estimations, we assume that a strong distortion of the director field in large droplets take place only in the near-surface regions, while the majority of NLC molecules are reoriented under the action of the magnetic field as a homogeneous volume. Using this approximation and taking into account the anisometry (aspect ratio) of droplets [7], the NLC switch-on time can be determined from the equation of balance between the moments of elastic and viscous forces and the torque of the external field, which yields the following formula:

$$\tau_{onLC} = \frac{\gamma_1}{\Delta\chi(H^2 - H_0^2) + \frac{K(l^2-1)}{a^2}}, \quad (1)$$

where γ_1 is the rotational viscosity coefficient; $K = (K_{11} + K_{22} + K_{33})/3$ is the effective elastic modulus defined as the arithmetic mean of the moduli of transverse bending, torsion, and longitudinal deformation of the NLC; and $\Delta\chi$ is the anisotropy of the magnetic susceptibility. Substituting the data for 5CB at 24°C ($K_{11} = 6.42 \times 10^{-12}$ N, $K_{33} = 8.6 \times 10^{-12}$ N [8], $K_{22} = 3 \times 10^{-12}$ N [9], $K = 6 \times 10^{-12}$ N, $\Delta\chi = 1.16 \times 10^{-7}$ [8], $\gamma_1 = 0.082$ N s/m^2 [10]) and the known experimental parameters ($l = 1.4$, $2a = 10.5$ μm, $H = 9 \times 10^6$ A/m, $H_0 \approx 8.8 \times 10^5$ A/m) into formula (1), we obtain $\tau_{onLC} \approx$ 0.81 ms, which is significantly smaller than the magnetic pulse front width τ_{onH}. Therefore, the NLC director can follow variations of the pulsed field as well as the slowly varying (constant) field. The coincidence of the peaks of curves *1* and *2* (Fig. 3) on the time scale indicates that the optical transmission does not exhibit saturation. This circumstance implies that, despite the significant *H* value, NLC molecules at the capsule boundary are not oriented along the field, which is characteristic of a strong interaction between 5CB and the PVB surface. It should be also noted that the second term in the denominator of expression (1) only provides a small correction to the τ_{onH} value, so that the response rising time is determined by the field amplitude rather than by the droplet size and aspect ratio.

The NLC relaxation time can be expressed as follows [7]:

$$\tau_{offLC} = \frac{\gamma_1 a^2}{K(l^2-1)}. \quad (2)$$

Substituting the above data into this formula yields τ_{offLC} = 392 ms, which is somewhat greater than the value obtained in experiment. The discrepancy is probably explained by the fact that the fixation of poles significantly affects the dynamic properties of the molecular ensemble of NLC in an ellipsoidal capsule. Formula (2), which is applicable within the framework of a model stipulating rotation of the director field as a whole, describes a particular case in the possible scenario of the internal structure transformation and can be used for evaluating the maximum relaxation time.

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REFERENCES

1. G. M. Zharkova and A. S. Sonin, *Liquid-Crystalline Composites* (Nauka, Novosibirsk, 1994) [in Russian].
2. G. Barbero and L. R. Evangelista, *Adsorption Phenomena and Anchoring Energy in Nematic Liquid Crystals* (Taylor and Francis, Boca Raton, 2006).
3. O. O. Prishchepa, V. F. Shabanov, V. Ya. Zyryanov, A. M. Parshin, and V. G. Nazarov, Pis'ma Zh. Éksp. Teor. Fiz. **84**, 723 (2006) [JETP Lett. **84**, 602 (2005)].
4. A. V. Barannik, O. O. Prishchepa, A. M. Parshin, A. V. Shabanov, V. G. Nazarov, and V. Y. Zyryanov, Proc. SPIE **6637**, 5 (2007).
5. A. S. Lagutin and V. I. Ozhogin, *Strong Pulsed Magnetic Fields in Physical Experiment* (Énergoatomizdat, Moscow, 1988) [in Russian].
6. D. Montgomery, *Solenoid Magnet Design* (Plenum, New York, 1969; Mir, Moscow, 1971).
7. B-G. Wu, J. H. Erdmann, and J. W. Foane, Liq. Cryst. **5**, 1453 (1989).
8. J. D. Bunning, T. I. Faber, and P. L. Sherrell, J. Phys. **42**, 1175 (1981).
9. M. J. Bradshaw, E. P. Raynes, J. D. Bunning, and T. I. Faber, J. Phys. **46**, 1513 (1985).
10. V. V. Belyaev, *Viscosity of Nematic Liquid Crystals* (Fizmatlit, Moscow, 2002) [in Russian].

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