Electro-Optical Characteristics of Polymer-Dispersed Liquid Crystal Film Controlled by Ionic-Surfactant Method

M. N. Krakhalev, V. A. Loiko, and V. Ya. Zyryanov*

*Kirensky Institute of Physics, Krasnoyarsk Scientific Center, Siberian Branch,
Russian Academy of Sciences, Krasnoyarsk, 660036 Russia*
Reshetnev Siberian State Aerospace University, Krasnoyarsk, 660014 Russia
Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, 220072 Belarus
*e-mail: zyr@iph.krasn.ru
Received August 24, 2010

Abstract—The electro-optical characteristics of a composite film based on a polymer containing dispersed nematic liquid crystal (NLC) doped with an ionic surfactant have been studied. The threshold character of the reorientation of NLC droplets as well as the dependence of the modulation amplitude of light transmission on the electric field strength has been revealed for the effect of ionic modification of surface anchoring. The dynamical parameters of the optical response have been determined.

Polymer-dispersed liquid crystals (PDLCs) are among promising materials for the new field of optoelectronic technology, which is related to the fabrication of flexible electro-optic devices, including displays [1]. A PDLC material usually has the form of a polymer film containing encapsulated LC droplets. These films are highly attractive due to the successful combination of the advantages of both polymers and liquid crystals (LCs), including flexibility, good mechanical strength, simple fabrication technology, low control voltages, and small energy consumption.

Recently [2], we proposed and implemented a new method of controlling the orientational structure of LC droplets, which is based on the modification of their surface anchoring by electric-field-driven ionic surfactants. We believe that the development of this approach can lead to the creation of principally new LC materials capable of significantly expanding the functional possibilities of optoelectronic devices. This Letter presents the results of an investigation of the electro-optical characteristics of a PDLC film controlled by the ionic-surfactant method.

The polymer matrix of PDLC films was poly(vinyl alcohol) (PVA) plasticized by glycerol (Gl). The nematic liquid crystal (NLC), representing 4-n-pentyl-4'-cyanobiphenyl (5CB) doped with a cationic surfactant (cetyltrimethylammonium bromide, CTAB), was encapsulated in the PVA matrix using the well-known emulsification technique [3]. The ratio of components in the obtained PVA–Gl–5CB–CTAB composition was 9.3:3.7:1:0.02 by weight. The indicated CTAB content was sufficient to ensure normal boundary conditions at the LC–polymer interface, so that a radial distribution of the LC director field was formed inside the

NLC droplets in the initial state. These conditions are characteristic of the inverse regime of ion modification of the interface [4].

The LC droplets had an average diameter of 2–3 μm in plane of the film that had a thickness of about 16 μm. The sample film was formed on a glass substrate with two stripe electrodes spaced by 1 mm. Thus, the field between the electrodes was oriented predominantly parallel to the PDLC film. The voltage applied to the electrodes had the shape of rectangular monopolar pulses of variable duration and amplitude. The orientational structure of LC droplets in the film was observed using a POLAM P-113 polarization microscope.

The electro-optical characteristics of the PDLC film were studied using radiation of a Mitsubishi ML 101J21-01 semiconductor laser operating at $\lambda = 658$ nm. The laser radiation was sequentially transmitted through the polarizer, sample, and diaphragm and then measured by a photodetector. The diameter of the beam cross section was about 0.8 mm. Scattered radiation was blocked by the diaphragm, so that only the directly transmitted light was detected. The cell with a sample film was oriented so that the electric field was perpendicular to the laser beam and the plane of light polarization.

NLC droplets in the initial state observed in the geometry of crossed polarizers exhibit structures of the Maltese cross type, which are characteristic of a radial director configuration with a point defect at the droplet center. The structure remains almost unchanged under the action of an applied electric field with a strength of up to 0.03 V/μm. As the field strength is increased further, the part of the interface that occurs
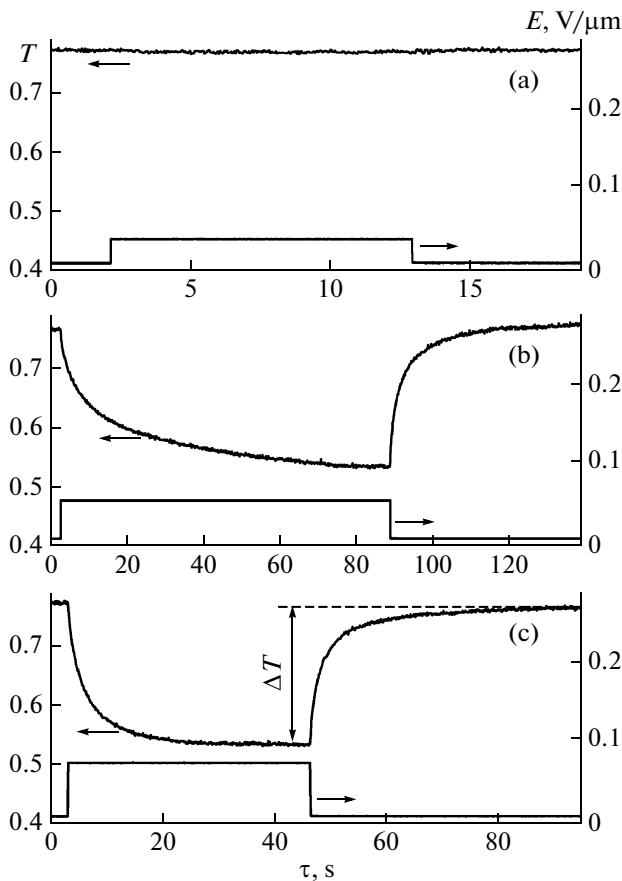
Fig. 1. Typical waveforms of the optical response of a PDLC film to electric field pulses of various amplitudes E (V/µm): (a) 0.03; (b) 0.05; (c) 0.07.

Fig. 2. Plot of the optical transmission modulation amplitude ΔT versus applied electric field strength E for the PDLC film.

closer to the anode becomes free of CTA^+ surfactant ions and, as a result, tangential boundary conditions (characteristic of the given polymer) are restored in this surface region. For this reason, the configuration of the LC director is transformed so that the fraction of the droplet surface that produces strong scattering of the incident radiation sharply increases. These changes in the orientational structure of NLC droplets are clearly manifested in the macroscopic optical response.

Figure 1 shows the typical waveforms of the optical response of a PDLC film to electric field pulses of various amplitudes. The optical transmission T of the film in the forward direction for a normally incident light was 0.77 in the absence of an applied field and for a field strength of up to $E = 0.03$ V/µm (Fig. 1a). The application of a field with $E = 0.04$ V/µm leads to a decrease in the optical transmission, which can be naturally explained (in the employed scheme of measurements) by the enhanced scattering of light by the NLC droplets with a modified orientational structure. After switching off the field, the transmission is restored to the initial level within a time of approximately 11 s.
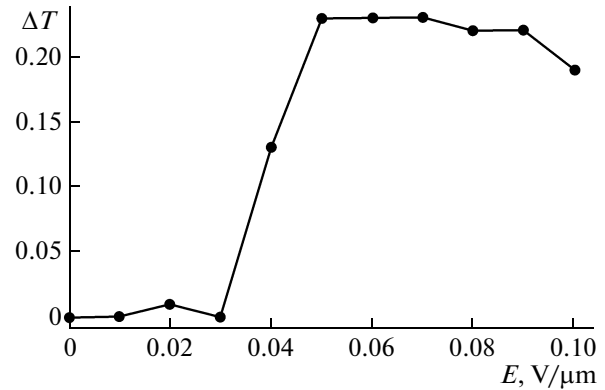
The dependence of the transmission change, $\Delta T \sim E$, exhibits saturation at $E = 0.05$ V/µm (Fig. 1b), for which it reaches a level of $\Delta T \sim 0.23$ (Fig. 2). This value of ΔT is retained as the field strength is increased up to $E = 0.07$ V/µm (Fig. 1c) and decreases with further growth in the field strength.

Analogous variations can be traced for the field dependences of the dynamic parameters of the optical response (Fig. 3). The response switch-on time τ_{on} decreases to 10 s at $E = 0.07$ V/µm, which is explained by a diffusion character of the ion motion. Indeed, the higher the field strength, the shorter time is sufficient to destroy the screening layer of ionic surfactant at the surface of NLC droplet. However, this tendency is only retained until $E = 0.07$ V/µm. As the field strength increases further, the τ_{on} value begins to increase, exhibits a local maximum at $E = 0.08$ V/µm, and then drops again. Elucidating the reasons for this behavior requires additional investigation. In contrast, the relaxation process exhibits no such a strong dependence on the applied field amplitude. The relaxation time varies within $\tau_{off} = 10-20$ s. In the interval of field amplitudes up to $E = 0.08$ V/µm, this value first somewhat increases and then begins to decrease.

Thus, using the ionic-surfactant method to modify the surface anchoring of NLC droplets in PDLCs, it is possible to transform the orientational structure of LCs and, hence, to control the macroscopic optical characteristics of these composite films. A specific feature of this method is the use of a dc electric field, whose switch-off leads to recovery of the initial LC state. The optical response exhibits a threshold character of its dependence on the applied field strength. In a sample used in this study, the reorientation proceeds rather slowly, with a minimum response and relaxation times of about 10 s. However, it is not excluded that the response speed may be increased by optimizing the composition and structure of the material. An evident advantage of the proposed approach is the small strength of the control field, which is lower
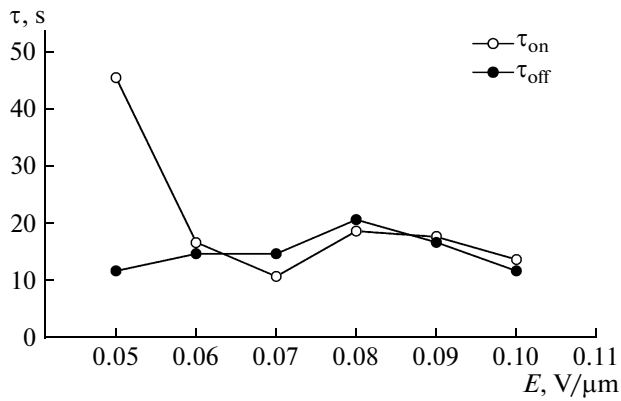
Fig. 3. Plots of the optical response time (τ_{on}) and relaxation time (τ_{off}) versus applied electric field strength E for the PDLC film.

by an order of magnitude compared to that for PDLC films with analogous structures [5] that operate based on the Freedericksz effect.

REFERENCES

1. *Flexible Flat Panel Displays*, Ed. by G. P. Crawford (John Wiley & Sons, Hoboken, 2005).
2. V. Ya. Zyryanov, M. N. Krakhalev, O. O. Prishchepa, and A. V. Shabanov, Pis'ma Zh. Eksp. Teor. Fiz. **86**, 440 (2007) [JETP Letters **86**, 383 (2007)].
3. P. S. Drzaic, *Liquid Crystal Dispersions* (World Scientific, Singapore, 1995).
4. V. Ya. Zyryanov, M. N. Krakhalev, O. O. Prishchepa, and A. V. Shabanov, Pis'ma Zh. Eksp. Teor. Fiz. **88**, 688 (2008) [JETP Letters **88**, 597 (2008)].
5. J. W. Doane, MRS Bulletin **16**, 22 (1991).

Translated by P. Pozdeev