ISSN 0030-400X, Optics and Spectroscopy, 2020, Vol. 128, No. 3, pp. 331–338. © Pleiades Publishing, Ltd., 2020.
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PHYSICAL OPTICS

Small-Angle Scattering and Radiation Polarization by a Stretched Polymer Film with Nematic Liquid Crystal Droplets Having a Single-Domain Structure

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Received November 1, 2019; revised November 1, 2019; accepted November 21, 2019

Abstract—The coefficient of directed transmittance of a stretched polymer-dispersed liquid crystal film with a defect-free single-domain liquid crystal droplet structure formed by a stretched surfactant-doped film and the polarization degree of forward-transmitted light in the visible and near-infrared spectrum ranges are studied. Results are presented for the 5CB, E7, and E44 nematic liquid crystals. Dependences of the transmission coefficient and polarizing ability of the film on the photodetector field of view are studied. Relationships allowing one to determine film parameters at which the transmission coefficient and polarizing ability of the films simultaneously reach values close to limit ones (0.5 and ±1.0, respectively) are obtained in the Foldy–Twersky and anomalous diffraction approximations.

Keywords: light scattering, radiation polarization, liquid crystal

DOI: 10.1134/S0030400X20030121

INTRODUCTION

Using polymer-dispersed liquid crystal (PDLC) films for polarization of light allows one to significantly increase the limit of the power of the incident light flux [1]. They make it possible to polarize radiation with an incident flux power density up to 2 kW/cm^2 [2, 3] and higher, when usual film polarizers (polariods) [4] with absorption anisotropy break due to heating. PDLC films consisting of elongated oriented liquid crystal (LC) droplets in a polymeric matrix [1–3, 5–10] possess light scattering anisotropy and effectively polarize the radiation in the whole transparency region of the used components (visible and near-IR regions), whereas polariods do it only in the dichroic band of the intrinsic or extrinsic absorption. For such films, there appears an additional possibility for control and modulation of the optical response by the action of an electric or magnetic field. They are especially promising for applications in laser and projection devices.

Recently, a new method of control for the optical response of PDLC films in the light scattering mode was implemented. The method is based on the local Fréedericksz effect [11–14]. The essence of this effect is that the structure of the director field in droplets of a nematic LC changes due to the inhomogeneous interfacial anchoring at the droplet–polymer interface. The anchoring inhomogeneity is created by using surface active agents (surfactants). This way of control for the internal structure of droplets allows one to form in them an almost homogeneous (single-domain) orientation of local optical axes in the process of mechanical stretching of the film. This leads to a significant increase in the light polarization efficiency [15–17] as compared to ways based on homogeneous interfacial surface anchoring.

The optomechanical model for describing the coefficient of coherent (directed) transmission and polarizing ability of a PDLC film with elongated droplets of a liquid crystal was developed in [17]. It is based on the Foldy–Twersky and anomalous diffraction approximations. The model describes the optical response of a stretched film depending on the film thickness, refractive index of the polymer, size and anisometry parameters of LC droplets, their concentration, internal structure, polydispersity, and orientation of the optical axes. However, the model considers only the directional transmittance of the film and the polarization degree of forward-transmitted light.

The model developed in this work takes into account not only the forward-transmitted but also the scattered radiation. It generalizes results described in [17]. The model allows one to analyze (i) the angular distribution of light scattered into the forward hemisphere and (ii) the transmission and polarizing ability of elongated PDLC films with allowance for the field-of-view of the detector.

The numerical analysis is carried out for spectral dependences of the coherent transmission coefficient and polarizing ability of a stretched nonabsorbing PDLC film with a single-domain structure of droplets with ion-surfactant modification of the interfacial surface anchoring in the visible and near-infrared spectrum ranges. The effect of the refractive index of the polymer matrix on spectral dependences of transmission and polarizing ability of a PDLC film containing droplets of 5CB, E7, and E44 nematic liquid crystals, as well as the effect of the field of view on transmission and polarizing ability, are studied.

MAIN RELATIONSHIPS

Coherent Transmittance and Polarizing Ability of a Stretched Film

The schematic image of the PDLC layer structure under stretching along the y axis is presented in Fig. 1. A plane-parallel PDLC layer under unidirectional mechanical stretching along the y axis is illuminated along the normal (along the x axis) by a nonpolarized radiation. The yz plane coincides with the front surface of the layer; $\mathbf{N}_j$ is the optical axis (director) of the jth droplet; φ is the angle of the droplet optical axis orientation relative to the y axis; a, b, and c are the semiaxes of elongated ellipsoidal droplets; l is the thickness of the stretched layer; and l_y and l_z are its linear dimensions along the y and z axes of the laboratory coordinate system xyz.

Let us define coherent (directed) transmittance T_c^{np} and polarizing ability P_c of the layer as follows:

$$T_c^{np} = \frac{T_\parallel^c + T_\perp^c}{2}, \quad (1)$$

$$P_c = \frac{T_\perp^c - T_\parallel^c}{T_\parallel^c + T_\perp^c}, \quad (2)$$

where $T_\parallel^c$ and $T_\perp^c$ are the layer transmittances determined in the parallel polarizer and analyzer positioned along stretching axis y and orthogonally to it, respectively.

Using the Foldy–Twersky approximation [17, 18], we write

$$T_{\parallel,\perp}^c = \exp(-\gamma_{2,1} l), \quad (3)$$

$$\gamma_2 = \frac{4\pi}{k^2} N_v \left\langle \mathrm{Re}\, S_e^0 \cos^2\varphi + \mathrm{Re}\, S_o^0 \sin^2\varphi \right\rangle_{a,b,c,\mathbf{N}_j}, \quad (4)$$

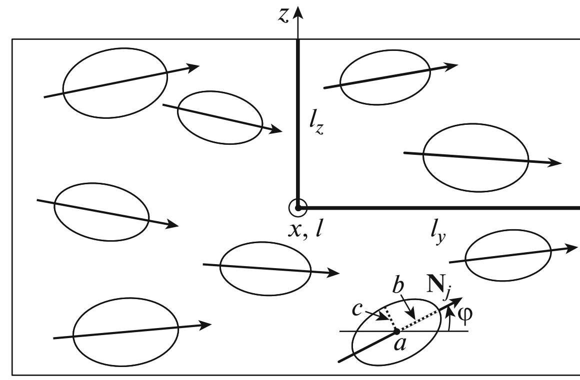

Fig. 1. Schematic image of the PDLC layer structure under stretching along the y axis. xyz is the laboratory coordinate system; the yz plane coincides with the front surface of the layer; φ is the orientation angle of the optical axis $\mathbf{N}_j$ of an individual droplet; l and l_y, l_z are the thickness of the stretched layer and its linear dimensions along the y and z axes, respectively; and a, b, and c are semiaxes of elongated ellipsoidal droplets. The layer is illuminated along the normal (along the x axis) by nonpolarized radiation.

$$\gamma_1 = \frac{4\pi}{k^2} N_v \left\langle \mathrm{Re}\, S_e^0 \sin^2\varphi + \mathrm{Re}\, S_o^0 \cos^2\varphi \right\rangle_{a,b,c,\mathbf{N}_j}, \quad (5)$$

where γ_2 and γ_1 are the extinction indices of layer for the y- and z-polarizations of incident light, $k = 2\pi n_p/\lambda$; n_p is the refractive index of the polymer matrix, λ is the wavelength of incident light, N_v is the number of LC droplets in a unit volume, and $S_{e,o}^0$ are elements of the amplitude scattering matrix of an individual droplet [18–20] at a zero scattering angle for an extraordinary (subscript e) and ordinary (subscript o) waves with polarizations along and transversely to the optical axis $\mathbf{N}_j$. At the same internal structure of droplets, the angular brackets in expressions (4) and (5) mean averaging over the droplet sizes a, b, and c and orientation of their optical axes.

Let us assume that the layer before the stretching consists of polydispersed spheroidal (or spherical) droplets with semiaxes a_0 and c_0. Semiaxes a_0 are oriented along the x axis, and semiaxes c_0, parallel to the yz plane. For spheroids, $a_0 < c_0$ (for spheres, $a_0 = c_0$). We assume that the anisometry parameters (ratios of the axes) are the same for all droplets in the initial state of the layer and changed identically during the stretching. Then, using the anomalous diffraction approximation for elements of the amplitude scattering matrix $S_{e,o}^0$ and the mean value theorem [19, 21], we write expressions for extinction indices $\gamma_{2,1}$:

$$\gamma_2 = \frac{3c_v}{4a_{ef}} \left\{ Q_e(a_{ef}) \frac{1 + S_{2f}}{2} + Q_o(a_{ef}) \frac{1 - S_{2f}}{2} \right\}, \quad (6)$$

$$\gamma_1 = \frac{3c_v}{4a_{\rm ef}}\left\{Q_{\rm e}(a_{\rm ef})\frac{1-S_{2f}}{2} + Q_{\rm o}(a_{\rm ef})\frac{1+S_{2f}}{2}\right\}, \quad (7)$$

$$Q_{\rm e,o}(a_{\rm ef}) = 2\,{\rm Re}\int\limits_{\sigma=\pi bc}(1-T_{2,1}(a_{\rm ef}))d\sigma, \quad (8)$$

$$S_{2f} = 2\overline{\cos^2\varphi} - 1, \quad (9)$$

$$a_{\rm ef} = \langle a^3\rangle/\langle a^2\rangle. \quad (10)$$

Here, angular brackets $\langle ... \rangle$ mean averaging over size a of droplet semiaxes; c_v is the volume filling factor of layer (the ratio of the volume of all droplets to the volume of the layer in which they are distributed); $a_{\rm ef}$ is the effective value of the semiaxis length a; $Q_{\rm e,\,o}(a_{\rm ef})$ are the extinction efficiency factors of an individual droplet for extraordinary and ordinary waves; $T_{2,\,1}$ are diagonal elements of the Jones matrix of an equivalent amplitude–phase screen; and S_{2f} is the two-dimensional (2D) order parameter of the PDLC layer. The over-bar in expression (9) means averaging over the angle φ (Fig. 1) of the orientation of the droplet optical axes $\mathbf{N}_j$.

Under stretching of the film, its thickness l, droplet sizes a, b, and c, and anisometry parameters $\varepsilon_y = b/a$ and $\varepsilon_z = c/a$ vary as follows [22]:

$$l = l_0 p^{-B}, \quad (11)$$

$$a = a_0 p^{-B}, \quad b = c_0 p, \quad c = c_0 p^{-A}, \quad (12)$$

$$\varepsilon_y = b/a = (c_0/a_0)^{1+B}, \quad \varepsilon_z = c/a = (c_0/a_0)^{B-A}, \quad (13)$$

where $p = l_y/l_y^0$ is the stretching factor equal to the ratio of lengths l_y and l_y^0 of the considered part of the layer in the deformed ($p \neq 1$) and initial ($p = 1$) states and power indices A and B depend on mechanical properties of the polymer matrix ($A + B = 1$).

For elongated ellipsoidal droplets with the single-domain internal LC configuration, one can write analytical relationships [23] describing extinction efficiency factors $Q_{\rm e,\,o}$ as functions of size (effective size of semiaxis a) $a_{\rm ef}$:

$$Q_{\rm e,o}(a_{\rm ef}) = 4\,{\rm Re}\,K_{\rm e,o}(a_{\rm ef}), \quad (14)$$

where K is the Hulst function [19],

$$K_{\rm e,o}(a_{\rm ef}) = \frac{1}{2} + \frac{\exp(-\Delta_{\rm e,o}(a_{\rm ef}))}{i\Delta_{\rm e,o}(a_{\rm ef})} + \frac{\exp(-i\Delta_{\rm e,o}(a_{\rm ef}))-1}{(i\Delta_{\rm e,o}(a_{\rm ef}))^2}, \quad (15)$$

$$\Delta_{\rm e,o}(a_{\rm ef}) = 2ka_{\rm ef}\left(\frac{n_{\parallel,\perp}}{n_p} - 1\right). \quad (16)$$

In the analysis of transmission and polarization, we assumed that the refractive index of the polymer in the considered wavelength range depends on the wavelength much weaker than the refractive indices of the liquid crystal and treated it as constant. We took into account the dependence of LC refractive indices $n_\parallel$ and $n_\perp$ on wavelength λ using the Cauchy formula:

$$n_{\parallel,\perp} = A_{\parallel,\perp} + \frac{B_{\parallel,\perp}}{\lambda^2} + \frac{C_{\parallel,\perp}}{\lambda^4}. \quad (17)$$

Values of coefficients $A_{\parallel,\,\perp}$, $B_{\parallel,\,\perp}$, and $C_{\parallel,\,\perp}$ for the nematic LCs studied in this work are presented in Table 1.

Table 1. Values of coefficients $A_{\parallel,\,\perp}$, $B_{\parallel,\,\perp}$, and $C_{\parallel,\,\perp}$ for 5CB, E7, and E44 LCs [24]

LC	$A_\parallel$	$B_\parallel$	$C_\parallel$	$A_\perp$	$B_\perp$	$C_\perp$
5CB	1.6708	0.0081	0.0024	1.5139	0.0052	0.0008
E7	1.6933	0.0078	0.0028	1.4990	0.0072	0.0003
E44	1.7282	0.0121	0.0027	1.5006	0.0091	0.0001

Intensity and Polarization Degree of Incoherently Scattered Light

Intensity $I_{\rm np}^{\rm inc}$, polarization degree $P_{\rm inc}$, and parallel $I_\parallel^{\rm inc}$ and orthogonal $I_\perp^{\rm inc}$ (to the stretching direction) intensity component of incoherently (diffusely) scattered radiation under illumination by nonpolarized radiation are determined as follows:

$$I_{\rm np}^{\rm inc} = \frac{1}{2}(I_\parallel^{\rm inc} + I_\perp^{\rm inc}), \quad (18)$$

$$P_{\rm inc} = \frac{I_\perp^{\rm inc} - I_\parallel^{\rm inc}}{I_\parallel^{\rm inc} + I_\perp^{\rm inc}}, \quad (19)$$

$$I_{\parallel,\perp}^{\rm inc} = (I_{vv}^{\rm inc} + I_{vh}^{\rm inc})\big|_{\alpha=0,\pi/2}. \quad (20)$$

Here, $I_{vv}^{\rm inc}$ and $I_{vh}^{\rm inc}$ are the vv- and vh-components of the intensity of radiation scattered by a film illuminated by a linearly polarized wave (vv is the polarization component parallel to the polarization plane of the incident wave, and vh is the polarization component orthogonal to the polarization plane of the incident wave) and α is the polarization angle (the angle between the polarization plane of the incident wave and stretching axis y).

If filling factor c_v of the layer is small ($c_v < 0.2$), one can use the single scattering approximation [19]. Within the framework of this approximation,

$$I_{vv,vh}^{\rm inc}(\theta_{\rm s},\varphi_{\rm s}) = C\frac{3}{4}\frac{l\langle a^2\rangle}{\varepsilon_y\varepsilon_z\langle a^3\rangle}\frac{c_v}{k^2\langle\sigma\rangle}\left\langle|f_{vv,vh}(\theta_{\rm s},\varphi_{\rm s})|^2\right\rangle_{a,\mathbf{N}_j}, \quad (21)$$

where θ_s and φ_s are the polar and azimuthal scattering angles, $C = \left|E_i^2\right| A/R^2$, E_i is the amplitude of the incident wave, A is the area of the illuminated part of the layer, R is the distance from the layer to the observation point, $\sigma = \pi bc$ is the cross section of droplets in layer plane yz, $f_{vv}(\theta_s, \varphi_s)$ and $f_{vh}(\theta_s, \varphi_s)$ are the vv- and vh-components of the vector amplitude scattering function of an individual LC droplet (they are determined in the parallel and crossed polarizer and analyzer, respectively), and the angular brackets $\langle\ldots\rangle_{a,\mathbf{N}_j}$ mean averaging over the size a and orientation of droplet optical axes $\mathbf{N}_j$ determined in the parallel and crossed polarizer and analyzer, respectively.

Incoherent Transmission and Polarizing Ability As a Function of the Field of View

Using angular distribution of the scattered light intensity (21), let us write formulas describing the dependence of incoherent transmittance $T_{\rm np}^{\rm inc}(\theta_{\rm fov})$ and polarizing ability $P_{\rm inc}(\theta_{\rm fov})$ of the PDLC film on field of view $\theta_{\rm fov}$:

$$T_{\rm np}^{\rm inc}(\theta_{\rm fov}) = \frac{1}{2}(T_{\parallel}^{\rm inc}(\theta_{\rm fov}) + T_{\perp}^{\rm inc}(\theta_{\rm fov})), \quad (22)$$

$$P_{\rm inc}(\theta_{\rm fov}) = \frac{T_{\perp}^{\rm inc}(\theta_{\rm fov}) - T_{\parallel}^{\rm inc}(\theta_{\rm fov})}{T_{\parallel}^{\rm inc}(\theta_{\rm fov}) + T_{\perp}^{\rm inc}(\theta_{\rm fov})}, \quad (23)$$

$$T_{\parallel,\perp}^{\rm inc}(\theta_{\rm fov}) = \frac{1}{C_{\rm np}}\int_0^{2\pi} d\varphi_s \times \int_0^{\theta_{\rm fov}/2} (I_{vv}^{\rm inc}(\theta_s,\varphi_s) + I_{vh}^{\rm inc}(\theta_s,\varphi_s))\Big|_{\alpha=0,\pi/2} \sin\theta_s d\theta_s. \quad (24)$$

Here, $T_{\parallel}^{\rm inc}(\theta_{\rm fov})$ and $T_{\perp}^{\rm inc}(\theta_{\rm fov})$ are the parallel and orthogonal components of the incoherent transmittance of the layer (the polarizer and analyzer are parallel and positioned along ($\alpha = 0$) and orthogonally ($\alpha = \pi/2$) to the y axis of the laboratory coordinate system, respectively),

$$C_{\rm np} = C\frac{3}{4}\frac{c_v l\left\langle a^2\right\rangle}{\varepsilon_y\varepsilon_z\left\langle a^3\right\rangle}(\langle Q_{\parallel}\rangle + \langle Q_{\perp}\rangle), \quad (25)$$

$$\langle Q_{\parallel,\perp}\rangle = \left(\langle Q_{\rm e}\rangle\frac{1 \pm S_{2f}}{2} + \langle Q_{\rm o}\rangle\frac{1 \mp S_{2f}}{2}\right), \quad (26)$$

$$\langle Q_{\parallel}\rangle + \langle Q_{\perp}\rangle \equiv \langle Q_{\rm e}\rangle + \langle Q_{\rm o}\rangle, \quad (27)$$

where $\langle Q_{\parallel}\rangle$ and $\langle Q_{\perp}\rangle$ are the mean extinction efficiency factors of LC droplets for incident light polarizations parallel and orthogonal to the stretching axis and $\langle Q_{\rm e}\rangle$ and $\langle Q_{\rm o}\rangle$ are determined by formula (8).

To determine transmittance $T_{\rm np}(\theta_{\rm fov})$ of the layer and light polarization degree $P_{\rm fov}$, it is necessary to take into account the coherent $T_{\rm c}^{\rm np}$ and incoherent $T_{\rm np}^{\rm inc}(\theta_{\rm fov})$ components. The transmittance and polarization degree are determined as follows:

$$T_{\rm np}(\theta_{\rm fov}) = T_{\rm np}^{\rm c} + T_{\rm np}^{\rm inc}(\theta_{\rm fov}) = T_{\parallel}(\theta_{\rm fov}) + T_{\perp}(\theta_{\rm fov}), \quad (28)$$

$$P_{\rm fov}(\theta_{\rm fov}) = \frac{T_{\perp}(\theta_{\rm fov}) - T_{\parallel}(\theta_{\rm fov})}{T_{\parallel}(\theta_{\rm fov}) + T_{\perp}(\theta_{\rm fov})}, \quad (29)$$

$$T_{\parallel,\perp}(\theta_{\rm fov}) = \frac{1}{2}(T_{\parallel,\perp}^{\rm c} + T_{\parallel,\perp}^{\rm inc}(\theta_{\rm fov})). \quad (30)$$

CALCULATION RESULTS

This section presents results of the analysis of the spectral dependences of transmittance $T_{\rm c}^{\rm np}$ and polarizing ability P of a PDLC film for stretching factor p = 2.0 corresponding to the formation of single-domain structures of droplets after ion-surfactant modification of the interfacial surface anchoring.

Analysis of the relationships written above shows that main parameters determining the limit polarization characteristics of a PDLC film (transmittance $T_{\rm c}^{\rm np} = 0.5$ and polarization degree $P_{\rm c} = \pm 1$) are (i) the refractive index of the polymer matrix $n_{\rm p}$ which must be equal to the ordinary refractive index of the liquid crystal $n_{\perp}$ (or the extraordinary one $n_{\parallel}$) in the sample and (ii) the transverse (to the film stretching direction) size of LC droplets a which, together with the condition $n_{\rm p} = n_{\perp}$ (or $n_{\rm p} = n_{\parallel}$) determines the possibility of simultaneous reaching the limit values for $T_{\rm c}^{\rm np}$ and $P_{\rm c}$.

Figure 2 illustrates dependences $T_{\rm c}^{\rm np}(\lambda)$ and $P_{\rm c}(\lambda)$ for the 5CB LC at a = 0.7 μm, when $n_{\rm p} = n_{\perp}(\lambda)$ or $n_{\rm p} = n_{\parallel}(\lambda)$ at wavelengths λ = 0.62, 0.5, and 0.45 μm. It is seen that the change in polymer refractive index $n_{\rm p}$ from $n_{\rm p} = n_{\perp}$ to $n_{\rm p} = n_{\parallel}$ allows one to reach high transmission and effective polarization of light in a wide spectrum range. The chosen value of the transverse semiaxis of droplets (a = 0.7 μm) is optimal for reaching the values of $T_{\rm c}^{\rm np}$ and P close to limit ones ($T_{\rm c}^{\rm np} \approx$ 0.5 and $P \approx \pm 1.0$) for the film the parameters of which were presented in [17].

Figure 3 presents dependences $T_{\rm c}^{\rm np}(\lambda)$ and $P_{\rm c}(\lambda)$ for a PDLC film based on different LCs: 5CB, E7, and E44. It is seen that an increase in the LC optical anisotropy, which is higher for the E44 LC than for E7 and 5CB, allows one to increase the range of wavelengths with the limit polarizing ability of the film for directed light $P_{\rm c} \approx \pm 1.0$ (Figs. 3b, 3d).

Note that positive values of P mean that the forward-transmitted light is linearly polarized orthogonally to the direction of film stretching; negative values of P mean that the light is polarized parallel to the stretching direction. The polarization sign is deter-

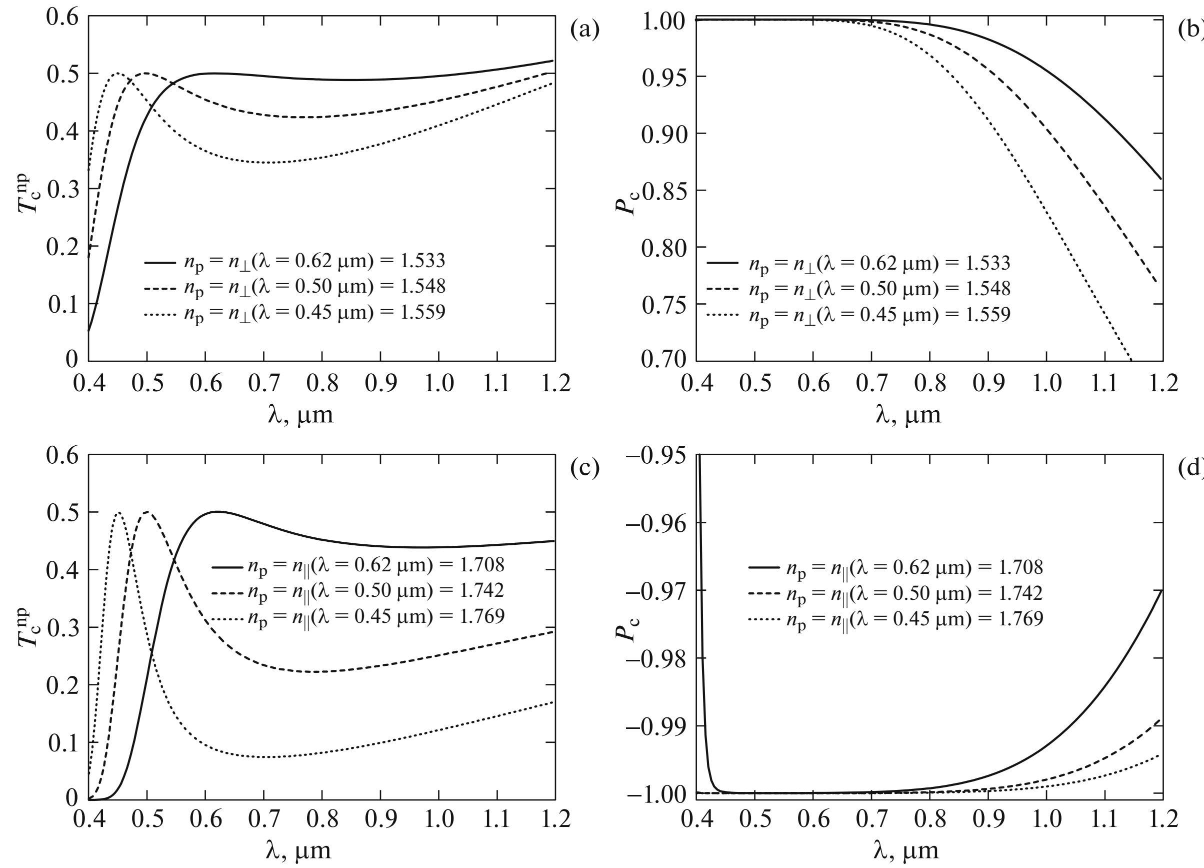

Fig. 2. Spectral dependences (a, c) $T_c^{np}(\lambda)$ and (b, d) $P_c(\lambda)$. Refractive index of the polymer n_p = (a, b) $n_\perp$ and (c, d) $n_\parallel$ at wavelengths $\lambda = 0.62$, 0.5, and 0.45 μm. 5CB LC. $p = 2$. Monodispersed oriented droplets ($S_{2f} = 1$) with a single-domain structure. 5CB LC, $l = 32$ μm, $c_v = 0.143$, $a = 0.7$ μm, $\varepsilon_y = 2.83$, and $\varepsilon_z = 1.0$.

mined by the component (orthogonal or parallel to the stretching axis) that passes the film without scattering.

Figures 4 and 5 present calculation results for angular distributions of the normalized intensity of scattered light,

$$I_{np}^{norm}(\theta_s, \varphi_s) = I_{np}^{inc}(\theta_s, \varphi_s)/I_{np}^{inc}(\theta_s = 0, \varphi_s = 0), \quad (31)$$

and polarizing ability $P_{inc}(\theta_s, \varphi_s)$ of the film at stretching factor $p = 2$.

They were obtained for films with monodispersed oriented droplets in which the semiaxis $a = 0.7$ μm. The refractive index of the polymer $n_p = n_\perp(\lambda = 0.62\ \mu m) = 1.533$. The extraordinary refractive index of the LC $n_\parallel(\lambda = 0.62\ \mu m) = 1.708$. Anisometry parameters $\varepsilon_y = 2.83$ and $\varepsilon_z = 1$ ($b = 1.981$ μm, $c = 0.7$ μm).

It is seen from Figs. 4 and 5 that $I_{tr}^{norm}(\theta_s, \varphi_s)$ and $P_{inc}(\theta_s, \varphi_s)$ are periodic functions of azimuthal scattering angle φ_s. Polarizing ability of the film $P_{inc}(\theta_s, \varphi_s)$ does not depend on polar scattering angle θ_s. Such a character of dependence $P_{inc}(\theta_s)$ = const is determined by the condition $n_p = n_\perp$ and chosen droplet size a. The light polarized orthogonally to the stretching axis is not scattered; the light polarized along the stretching axis undergoes weak scattering. At values $\varphi_s = n\pi/4$ ($n = 0, 1, 2, ..., 8$), the polarizing ability reaches limit values $P_{inc} = \pm 1$ for any values of the polar scattering angle θ_s from the considered range of scattering angles $-8° < \theta_s < 8°$. $P_{inc}(\theta_s) = +1$ at $\varphi_s = 0°, 90°, 180°, 270°$, and 360°. $P_{inc}(\theta_s) = -1$ at $\varphi_s = 45°, 135°, 225°$, and 315°.

Limit values $P_{inc}(\theta_s) = \pm 1$ can be implemented in a rather wide wavelength interval including the visible and near-infrared spectrum ranges. Figure 6 presents transmittances $T_{\parallel,\perp}^{inc}$, $T_{\parallel,\perp}$, T_{tr}^{inc}, and T_{tr} and polarizations P_{fov}^{inc} and P_{fov} as functions of field-of-view θ_{fov}.

The results were obtained for a stretched film containing monodispersed oriented LC droplets with a single-domain internal structure. The film parameters are shown in the legends. They determine conditions under which the forward-transmitted light is com-

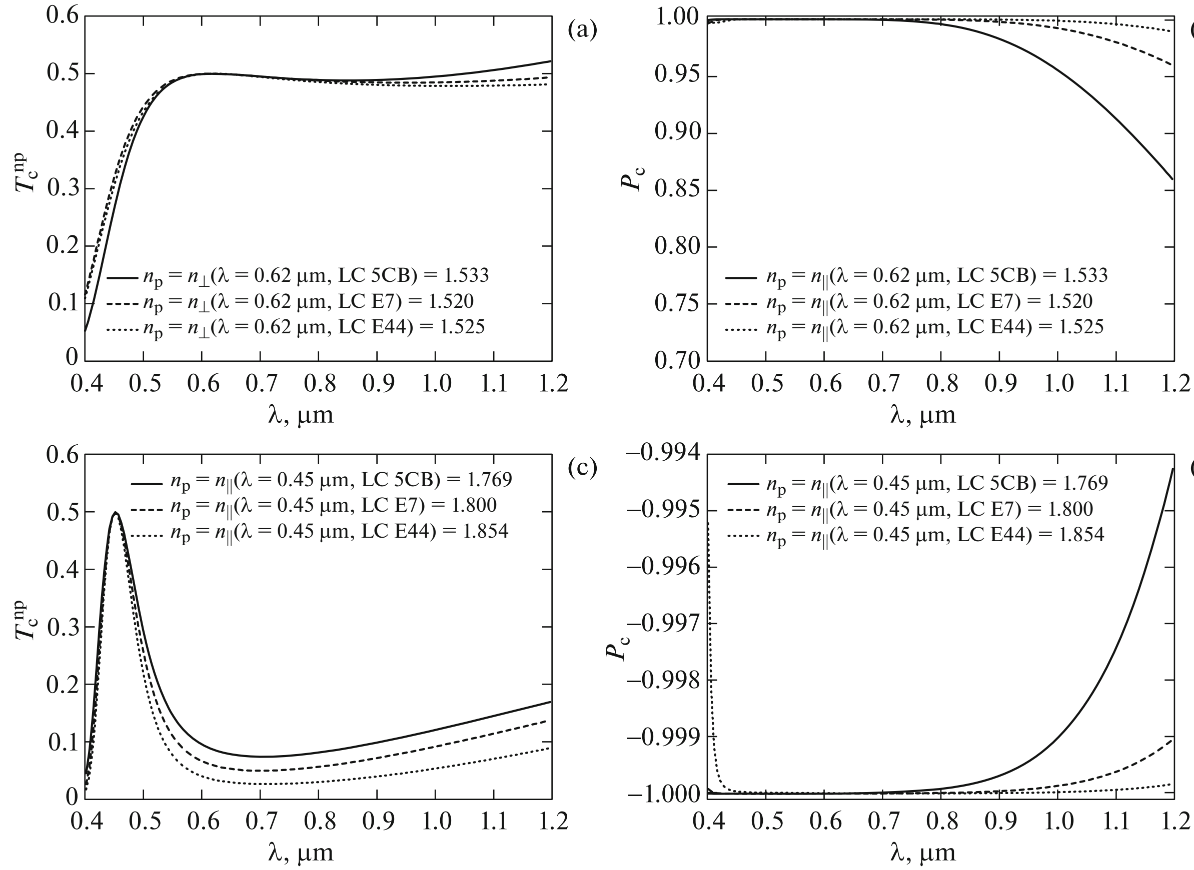

Fig. 3. Spectral dependences (a, c) $T_c^{np}(\lambda)$ and (b, d) $P_c(\lambda)$. Refractive index of the polymer n_p = (a, b) $n_\perp$ and (c, d) $n_\|$ at wavelengths λ = (a, b) 0.62, and (c, d) 0.45 μm. 5CB, E7, and E44 LCs. $p = 2$. Monodispersed oriented droplets ($S_{2f} = 1$) with a single-domain structure. $l = 32$ μm, $c_v = 0.143$, $a = 0.7$ μm, $\varepsilon_y = 2.83$, and $\varepsilon_z = 1.0$.

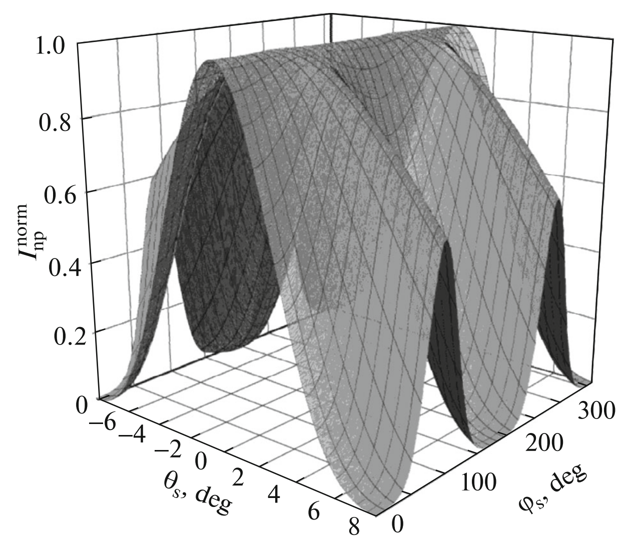

Fig. 4. Normalized scattered light intensity $I_{np}^{norm}(\theta_s, \varphi_s)$. Monodispersed oriented droplets ($S_{2f} = 1$) with a single-domain structure. Stretching factor $p = 2$. 5CB LC. $a = 0.7$ μm, $\varepsilon_y = 2.83$, and $\varepsilon_z = 1.0$. $A = B = 0.5$.

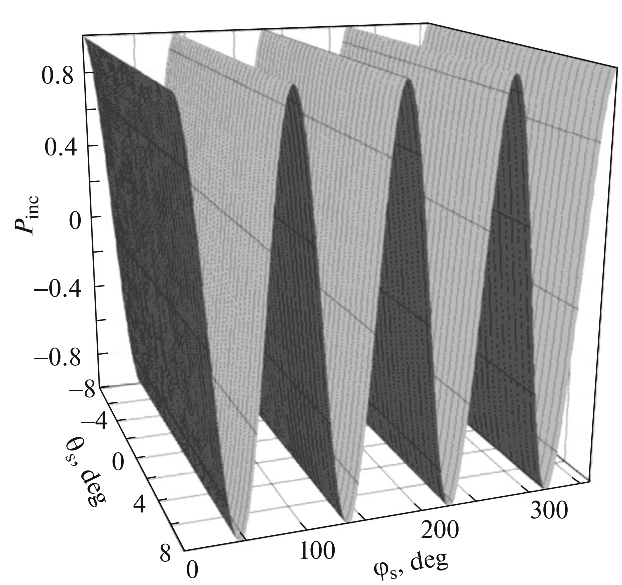

Fig. 5. Polarizing ability $P_{inc}(\theta_s, \varphi_s)$ of the PDLC film. Monodispersed oriented droplets ($S_{2f} = 1$) with a single-domain structure. Stretching factor $p = 2$. 5CB LC. $a = 0.7$ μm, $\varepsilon_y = 2.83$, and $\varepsilon_z = 1.0$. $A = B = 0.5$.

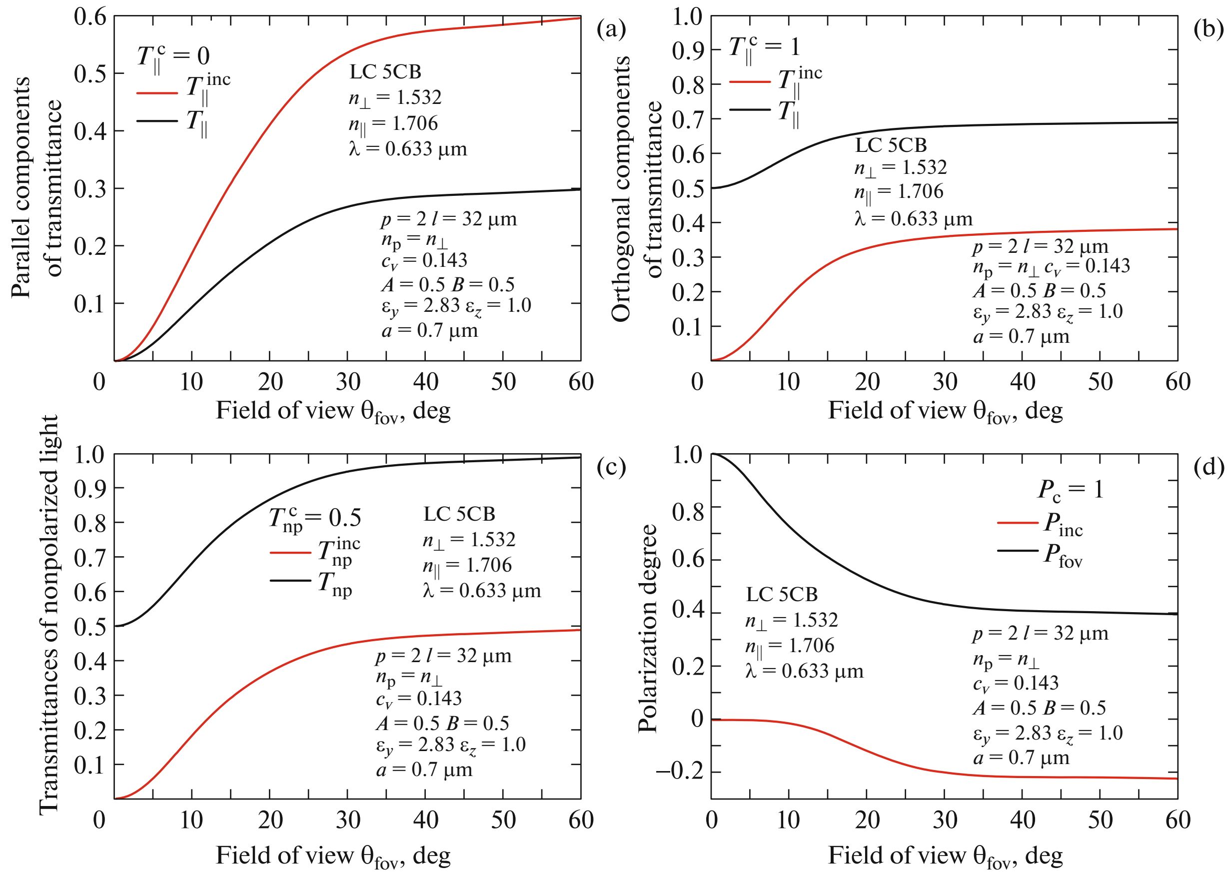

Fig. 6. Transmittance coefficients for the (a) parallel and (b) orthogonal components of scattered light, (c) transmittance coefficients for nonpolarized incident light, and (d) polarization degree as functions of field-of-view angle θ_{fov}. Monodispersed LC droplets with the single-domain structure. Stretching factor $p = 2$. $n_p = n_\perp = 1.532$. $\lambda = 0.633$ μm.

pletely polarized ($P_{fov} = 1$ at $\theta_{fov} = 0$) and coherent transmittance of the film $T_c^{np} = 0.5$.

It is seen from the presented data that almost all diffusely scattered light is recorded at field of view $\theta_{fov} = 60°$: total transmittance $T_{np}(\theta_{fov} = 60°) \approx 1$. The incoherent transmittance for nonpolarized incident light $T_{np}^{inc} \approx 0.5$ (Fig. 6c). The forward-transmitted light is partially polarized with polarization degree $P_{fov} \approx 0.4$ (Fig. 6d). The polarization degree of diffusely scattered light is negative and equal to approximately –0.22, which corresponds to a stronger scattering of the parallel component of the diffusely scattered light intensity as compared to the orthogonal component.

CONCLUSIONS

The method expounded in this work permits one to calculate optimum parameters of polaroids for specific practical conditions of their application, when it is necessary to take into account not only the coherent part of the transmitted radiation but also the part scattered incoherently.

Results of the numerical analysis of spectral dependences of the coherent transmittance and polarizing ability of a stretched nonabsorbing PDLC film with a single-domain droplet structure forming under ion-surfactant modification [15, 25] of the interfacial surface anchoring are presented. The spectra of coherent transmittance and polarizing ability of polymer–LC films based on the 5CB, E7, and E44 nematics are calculated. The results can be applied in developing polarizers operating in the light-scattering nonabsorbing mode. They possess high light-resistance, mechanical strength, transmittance, and polarizing ability.

Using PDLC films based on scattering of radiation allows one to significantly increase the power of the polarized incident light flux as compared to usual dichroic film Polaroids based on absorption of the incident radiation. In addition, the optical response of PDLC films can be changed by action of an electric field and, thus, the electrically controlled modulation of the polarization degree and light transmission can be provided.

FUNDING

This work was carried out within the framework of the agreement on interacademic collaboration between the National Academy of Sciences of Belarus and Siberian Branch of the Russian Academy of Sciences. It was supported by the Belarusian Republican Foundation for Fundamental Research (project no. F18RA-003). M.N. Krakhalev acknowledges the support of the Russian Foundation for Basic Research, the Government of Krasnoyarsk krai, and Krasnoyarsk Krai Foundation of Science (grant no. 18-42-243006).

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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