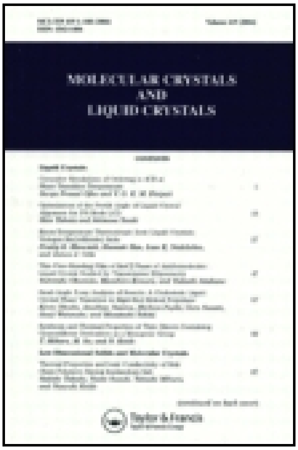

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Polarization of wave transmitted through a PDLC film with nanosized droplets

Valery Loiko* [a], Alexander Konkolovich [a] & Alexander Miskevich [a]
[a] Institute of Physics of NASB, Minsk, Belaru

Version of record first published: 18 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 422, pp. 237/[507]–242/[512], 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490502797

POLARIZATION OF WAVE TRANSMITTED THROUGH A PDLC FILM WITH NANOSIZED DROPLETS

Valery A. Loiko,* *Alexander V. Konkolovich*
and Alexander A. Miskevich
Institute of Physics of NASB, F.Scaryna ave. 68
Minsk, 220072, Belarus

A method to describe propagation of a linearly polarized plane wave through a polymer dispersed liquid crystal (PDLC) film is proposed. It is based on the Foldy-Twersky integral equation and anisotropic dipole approximation. Elliptical and circular polarization, rotation of the polarization plane of a transmitted wave at normal illumination of a PDLC film are investigated.

Keywords: nanosized droplets; polarization; transmitted mode

1. INTRODUCTION

Polymer dispersed liquid crystal (PDLC) films are widely used in optoelectronics to make compact display units, control and modulation of light beams [1,2]. PDLC films allow one to increase the functional utilities of optical devices. Nanosized PDLC films open new opportunities to develop simple constructions of known liquid crystal (LC) devices [3,4].

We have carried out the theoretical analysis of the transformation of a polarization state of a plane wave, passed through a PDLC film with aligned nanosized nematic LC droplets. We assume rotational symmetry of the orientation of LC molecules in a droplet. Elliptic and circular polarization, rotation of a polarization plane of a transmitted wave are investigated at normal illumination of a PDLC film by a linearly polarized plane wave.

The problem is considered within the framework of the classical method of scattering media optics [5,6]. First, a problem of scattering by a separate LC droplets is solved, and then the coherent field is determined to analyze the polarization state of a directly transmitted wave. In the proposed

The research was supported in part by the FFR of Belarus (Project F01-042).
*Corresponding author. Tel.: + 375 17 2842894, Fax: + 375 17 2840879, E-mail: loiko@dragon.bas-net.by

model, the order parameters characterizing ordering of LC molecules and droplet directors are used. Such an approach essentially simplifies a solution to the problem. It allowed us to relate amplitude, phase and polarization of a transmitted wave with morphological properties of a PDLC film, optical properties and structure of LC droplets.

The anisotropic dipole approximation [7] is used to determine the amplitude scattering matrix. To calculate a coherent field, an effective amplitude scattering matrix is introduced. It is determined by averaging the scattering matrix over the ensemble of LC droplets sizes, shapes and director axes orientation.

2. BASIC EQUATIONS

Consider a plane-parallel PDLC film with nano-sized liquid crystal droplets. Introduce a right-handed laboratory coordinate system (x, y, z) with z- axis directed along the normal to the PDLC film and (x, y) plane coinciding with the surface of the film. Let us assume that the film is illuminated by a plane wave with unit amplitude along z-axis. It is supposed that the configuration of droplets directors has a planar orientation near x-axis in the absence of the applied field. Under an applied field, the droplets directors reorient towards the direction of the normal to the PDLC film. In a strong field, all droplets directors are aligned in the same direction along z-axis and the homeotropic structure of the directors takes place.

Using the model to describe propagation of a coherent field via a PDLC film [4], we obtain the expressions for coherent field $\langle \underline{E} \rangle$ transmitted through the PDLC film:

$$\langle \underline{E} \rangle = E_x \underline{e}_x + E_y \underline{e}_y, \tag{1}$$

$$E_{x;y} = a_{e;o} \exp(-i\phi_{e;o}), \tag{2}$$

$$a_{e;o} = \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix} \exp\bigl(-(1/2)\gamma_{e;o} l\bigr), \tag{3}$$

$$\phi_{e;o} = ql \,\mathrm{Im}\langle S_{e;o}(0)\rangle, \tag{4}$$

where $\underline{e}_x$ and $\underline{e}_y$ are the units vectors along x- and y-axes, respectively; α is the polarization angle between the polarization vector of the incident wave and x-axis; γ_e and γ_o are the attenuation coefficients for the extraordinary and ordinary waves; l is the film thickness; $q = 2\pi k^{-3} N_v$, $k = 2\pi/\lambda_p$, λ_p is the wavelength of the incident light in the polymer matrix; N_v is the number of LC droplets per unit volume; $\langle S_e(0)\rangle$ and $\langle S_o(0)\rangle$ are the average amplitudes of scattering at zero scattering angle for the extraordinary and ordinary waves for a single droplet.

In the Rayleigh approximation for an anisotropic dipole [7], the average amplitudes of scattering and the attenuation coefficients can be determined as follows for a spherical droplet with cylindrical symmetry of the configuration of LC molecular axes:

$$\langle S_{e;o}(0)\rangle = -\frac{ik^3\langle v\rangle}{4\pi}\left(\frac{\varepsilon_{iso}}{\varepsilon_p} - 1 + \frac{2}{3}\Delta\varepsilon\, SS_d S_{x;y}\right), \tag{5}$$

$$\gamma_{e;o}(0) = \frac{8}{9}\langle x\rangle^4 f c_v \langle d\rangle^{-1}\left(\frac{\varepsilon_{iso}}{\varepsilon_p} - 1 + \frac{2}{3}\Delta\varepsilon\, SS_d S_{x;y}\right)^2, \tag{6}$$

where $\langle v\rangle$ is the average volume of a droplet; $\varepsilon_{iso} = (2\varepsilon_o + \varepsilon_e)/3$; $\Delta\varepsilon = \varepsilon_e - \varepsilon_o$, ε_e and ε_o are the dielectric constants of the LC for ordinary and extraordinary waves; $\langle x\rangle = \pi\langle d\rangle/\lambda_p$ is the average diffraction parameter; $\langle d\rangle$ is the average droplet diameter; λ_p is the wavelength of the incident light; $f = \langle d^3\rangle/(\langle d\rangle)^3$ is the ratio of the third moment of the droplet size distribution function to the cubic average diameter; $c_v = N_v\langle v\rangle$ is the volume concentration of droplets.

In Equations (5, 6) S and S_d are the molecular and droplet order parameters, respectively [2,8]; S_x and S_y are the x-and y-components of the order parameter tensor. The values of S_x and S_y are connected with z-order parameter S_z by the expressions:

$$S_x = \frac{1}{2}((1 - S_z)g - S_z), \tag{7a}$$

$$S_y = \frac{1}{2}((S_z - 1)g - S_z), \tag{7b}$$

where $g = \langle\cos^2\varphi\rangle - \langle\sin^2\varphi\rangle$; φ is the angle between the principal plane and plane (x, z) for a droplet; brackets $\langle\rangle$ means the average over the orientation of droplets directors in the PDLC film. At the transition of droplets directors from a planar structure to a homeotropic one, the value S_z changes in the range of $-1/2 < S_z < 1$. Note, that at cylindrical symmetry along z-axis or chaotic distribution of droplets directors, values $g = 0$ and $S_x = S_y$.

For the gamma-distribution of droplet diameters d and uniformly distribution of angle φ, the following equations take place [9]:

$$f = (1 + 2/\mu)(1 + 1/\mu), \tag{8}$$

$$g = \sin\mathrm{c}(2\varphi_m). \tag{9}$$

Here μ is the gamma-distribution parameter; φ_m is the maximum angle deviation of the droplet principal plane relative to the plane (x, z).

Generally, the electric vector of a coherent transmitted wave sweeps the polarization ellipse with axes turned by angle β with respect to x, y axes. For the semi-axes A and B of the polarization ellipse we can write:

$$tg2\beta = \frac{2a_e a_o}{a_e^2 - a_o^2}\cos(\phi_o - \phi_e), \tag{10}$$

$$A^2 = a_e^2\cos^2\beta + a_o^2\sin^2\beta + a_e a_o \sin 2\beta\cos(\phi_o - \phi_e), \tag{11}$$

$$B^2 = a_e^2\sin^2\beta + a_o^2\cos^2\beta - a_e a_o \sin 2\beta\cos(\phi_o - \phi_e). \tag{12}$$

On the basis of Eqs. (10)–(12), it is possible to find ellipsometric parameters, namely, azimuth ξ (angle between the major axis of the ellipse and x- axis counted clockwise) and ellipticity η (ratio of the small axis of the ellipse to the major one).

3. RESULTS

The ellipsometric parameters of the coherent transmitted field as a function of polarization angle α of the incident wave are shown in Figures 1 and 2.

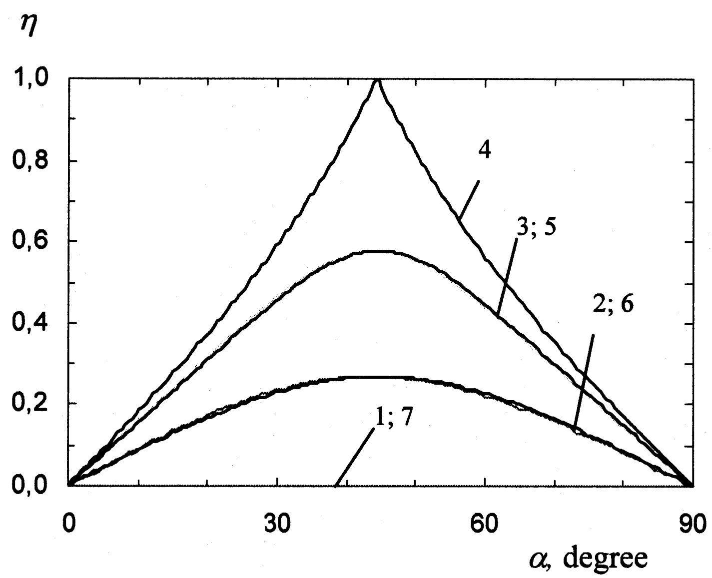

FIGURE 1 Dependence of ellipticity η on polarization angle α at different values of order parameter S_z. $\varepsilon_o = 2.283$; $\varepsilon_e = 3.028$; $\varepsilon_p = 2.323$; $\varphi_m = 5°$; $\mu = 15$; $l = 41\,\mu m$; $\langle d\rangle = 75\,nm$; $c_v = 0.075$; $S = 0.6$; $S_d = 0.7$; $S_z = -0.5$ (curve 1); $-0.25(2)$; 0 (3); 0.25 (4); 0.5 (5); 0.75 (6); 1.0 (7).

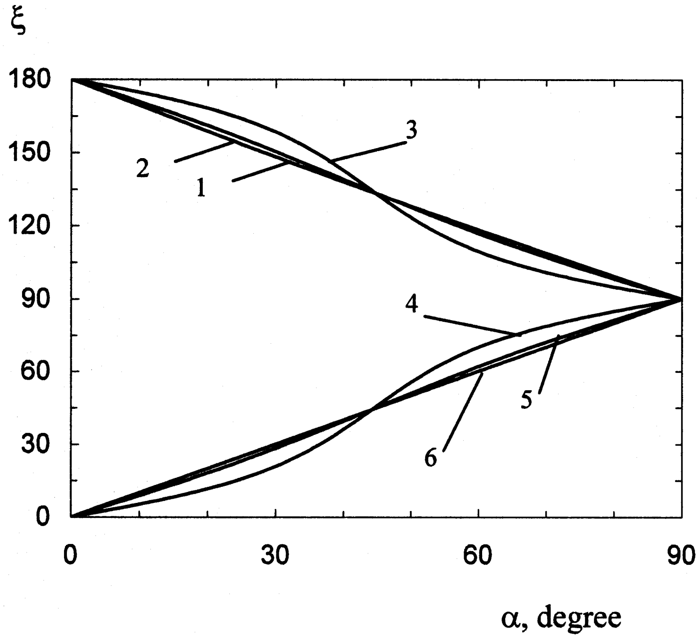

FIGURE 2 Dependence of azimuth ξ on polarization angle α at different values of order parameter S_z. $\varepsilon_o = 2.283$; $\varepsilon_e = 3.028$; $\varepsilon_p = 2.323$; $\varphi_m = 5°$; $\mu = 15$; $l = 41\,\mu$m; $\langle d \rangle = 75\,$nm; $c_v = 0.075$; $S = 0.6$; $S_d = 0.7$. $S_z = -0.5$ (curve 1); $-0.25(2)$; 0 (3); 0.5 (4); 0.75 (5); 1.0 (6).

Phase shift $\Delta\phi$ ($\Delta\phi = \phi_o - \phi_e$) changes in range $[\pi; 0]$ at the transition of the directors structure from planar oriented along x-axis ($S_x = 1$; $S_y = S_z = -1/2$) to the homeotropic one ($S_z = 1; S_x = S_y = -1/2$). This condition is achieved by a choice of film thickness l.

As seen from Figures 1 and 2, the transformation of the polarization state from linearly to elliptic and the rotation of the polarization plane of the incident wave are possible. The linear polarization of the transmitted wave corresponds to order parameter values S_z equal –1/2 and 1 ($\Delta\phi = \pi; 0$). At $a_e = a_o$ and $\Delta\phi = \pi/2$ ($S_z = 0.25$), the circular polarization of the coherent transmitted wave is achieved.

Pay attention that order parameter S_z depends on the applied field [2] and the range of phase shift $\Delta\phi$ $[\pi; 0]$ can be achieved at other values of the order parameter S_z by a choice of the film thickness. Thus, the solution to the optimization problem of the polarization state transformation in dependence on the applied field and PDLC film parameters is possible.

4. CONCLUSION

The transformations of the polarization state of a plane wave propagating through a PDLC film caused by the specific orientation of the droplet director structure was investigated.

The proposed model enables one to investigate the ellipsometric parameters of a coherent transmitted wave in dependence on the applied filed for different types of LCs.

Obtained results can be used to develop and design polarizers based on PDLC films with nano-sized droplets.

REFERENCES

[1] Crawford, G. P. & Zumer, S. (1996). (Eds.), *Liquid crystals in complex geometries*. Taylor & Francis: London, UK.

[2] Simoni, F. (1997). *Nonlinear optical properties of liquid crystals and polymer dispersed liquid crystals*. World Scientific: Singapore.

[3] Lucchetta, L., Karapinar, R., Manni, A., & Simoni, F. J. (2002). *App. Phys.*, *91*, 6060.

[4] Loiko, V. A. & Konkolovich, A. V. (2003). *Journal of Experimental and Theoretical Physics*, *96*, 489.

[5] Ishimaru, A. (1978). *Wave propagation and scattering in random media*. Academic Press: New York.

[6] Ivanov, A. P. Dick, V. P., & Loiko, V. A. (1988). *Propagation of light in closely-packed disperse media*. Nauka i Tekhnika: Minsk.

[7] Bohren, C. F. & Huffman, D. R. (1983). *Absorption and scattering of light by small particles*. Wiley & Sons: New York.

[8] Kelly, J. & Palffy-Muhoray, P. (1994). *Mol. Cryst. Liq. Cryst.*, *243*, 11.

[9] Loiko, V. A. & Konkolovich, A. V. (2000). *J. Phys. D: Appl. Phys.*, *33*, 2201.