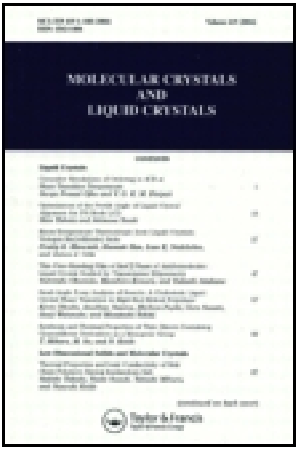

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Polarization features of polymer dispersed liquid crystal (PDLC) films were investigated experimentally. An alignment of PDLC films was achieved by a shear deformation of the films at an accurate control of geometric parameters. A numerical interpretation of experimental results was made for practical application An influence of droplets shape to the polarization features of the PDLC film was estimated.

Keywords: PDLC; nematic; polarization features; shear deformation

INTRODUCTION

The quantitative description of the light scattering in PDLC structure is very difficult[1]. The theory of light scattering from anisotropic droplets has been successfully developed by Zumer and Doane[2-4] which study the dependence of light scattering on the director orientation inside the droplet. In real working PDLC films arises several problematic aspects because the scattering LC droplets are anisotropic with rather substantial refractive index differences for highly birefringent LC. The director fields within the cavities often vary spatially. The shapes of the LC droplets are often irregular and the sizes of the LC droplets vary. Neighbouring droplets are often closely packed, with the relative orientation of adjacent cavities varying randomly. In high droplet densities the multiple scattering becomes an important factor[5].

The aim of this article are to estimate the factors to contributing to polarization features of the deformed PDLC structure.

Oriented PDLC film can polarize propagated light, that is to transmit only light beams of definite polarization. This feature of the oriented PDLC films is caused by a light scattering anisotropy, while usually the polarization phenomenon is caused by a light absorption anisotropy. This property enables using oriented PDLC films as polarizers in a broad spectral range, which should hold out larger energy in comparison with usual absorption-type polarizing films [6]. Moreover it's possible to change optical parameters of PDLC films by an application of external field to these films.

The model was developed for a description of the polarization - dependent scattering PDLC structure [6], based on an anomalous diffraction approximation method. The approximation results were compared with the experimental data [7]. This model fits well to the experimental data but for practical use it's too complicated and retains some indefinites. For example, it requires a precise knowledge of LC director orientation in an aligned PDLC structure (when droplets are deformed), what practically isn't easy attainable. It's not clear what an influence has an orientation of the LC director to optical parameters of PDLC films in deformed droplets. Here we try clear up these questions from a viewpoint of possible applications.

For practical application we use a crude geometrical approximation which assumes, that at start a PDLC structure is not deformed and all the droplets are of spherical shape and equal radius r_o. Later for simplicity we assume that light beam propagating through PDLC structure (thickness $d \gg r_o$) should meet LC molecules oriented along all the directions, independently how these molecules are situated inside the droplets. In this case a refractive index of LC in droplet would be equal to an average value of refractive index (only droplets are taken into account):

$$\bar{n}^2 = \frac{1}{3}\left(n_e^2 + 2\ n_o^2\right) \tag{1}$$

The transparency of the structure

$$T = I/I_o = e^{-(\gamma+\beta)d} \tag{2}$$

where γ- the scattering coefficient, β - the absorption coefficient.
The scattering coefficient

$$\gamma = N \; \pi \; r^2 \; \sigma \tag{3}$$

where N is the droplet density, r - the radius of the droplet, σ - the scattering cross section. The droplet density may be found experimentally because

$$N = V_{LC}/V_r \tag{4}$$

$$V_r = 4/3 \; \pi \; r_o^3 \tag{5}$$

r_0 being the radius of the spherical shape droplet.

In a common case σ the scattering cross-sections complicate and depends upon refractive index, light wavelength and upon the radii of scattering particles. However for some border cases there are simple expressions [8]. Real structures contain some ranges of the droplets radii where Rayleigh-Gans and anomalous diffraction approximations overlap. For not exact but an approximate solution an equation [8] is valid:

$$\sigma = 2\left(\bar{n}/n_p - 1\right)^2 \; x^2 \tag{6}$$

$$x = \frac{2 \; \pi \; r \; n_p}{\lambda} \tag{7}$$

n_p - refractive index of polymer, λ - light wavelength.

For a connection of transparency versus light polarization we make an assumption that an intensity of linearly polarized light scattered while passing through PDLC structure is caused by a number of LC droplets situated along the polarization direction. Spherical shape LC droplets are deformed to ellipsoids in shear deformed PDLC film. Such ellipsoids scatter propagating polarized light in such a manner, as if there would exist a set of spherical droplets with different radii. A subset of droplets with equal radii corresponds to one certain direction of polarization.

For a definite polarization the radius of droplet is equal to the diameter of half an ellipsoid, situated along the polarization direction. In general case (0<T<1) the variation of the transparency is given by

$$\ln T(\varphi) = -C\ \left(\bar{n} - n_p\right)^2\ r^4(\varphi)/r_o^3 - \beta\ d \tag{8}$$

where constant C can be expressed as

$$C = 6\ \pi^2\ V_{LC}\ d/\lambda^2 \tag{9}$$

The radius r(φ) for definite polarization equals

$$r^2(\varphi) = \frac{a^2\ b^2}{b^2 \cos^2 \varphi + a^2 \sin^2 \varphi} \tag{10}$$

where a and b - major and small semiaxis of the ellipsoid respectively. When laser beam entered PDLC structure which was rotated in a plane normal to the laser beam propagation direction, maximum and minimum of the transparency was recorded. In this situation we have two edge cases:

$$\ln T_{min} = -C\ \left(\bar{n} - n_p\right)^2\ a^4/b^3 - \beta\ d \tag{11}$$

$$\ln T_{max} = -C\ \left(\bar{n} - n_p\right)^2\ b - \beta\ d \tag{12}$$

then follow

$$b = -\ln T_{max} + \beta\ d \Big/ C\ \left(\bar{n} - n_p\right)^2 \tag{13}$$

$$a^4 = -\left(\ln T_{min} + \beta\ d\right)\ b^3 \Big/ C\ \left(\bar{n} - n_p\right)^2 \tag{14}$$

It follows from our experimental conditions that in a nondeformed PDLC structure the droplets radius r_o= b. We put (13) and (14) equations now to (10) and later to (8). Then we may easy determine the transparency for any linear polarization. Following our model it is not necessary to determine the diameter of droplets - the middle value of diameter is estimated directly from the transparency data.

EXPERIMENTAL RESULTS AND DISCUSSION

A polyvinylbutyral film with dispersed cyanobiphenyl type nematic LC mixture was used in our experiments. This PDLC film was prepared by a standard method using an evaporation of the solvent from common polymer - liquid crystal solution on the glass plate coated with transparent In_2O_3+SnO_2 electrode. The second glass electrode was fixed by a thermal welding. The $5cm^2$ square film with thickness $20\mu m$ was prepared. For the examination of the light polarization dependence on PDLC film scattering properties a shear deformation was used[9] .The force F=100N for an alignment of molecules in the nematic droplets was applied to the upper electrode (Figure1). In this case the shear deformation in the sample was homogenic and the Poisson coefficient was taken as being equal zero. In such a case an estimation of geometrical parameters of the films structure is simpler.

We consider that the volumes of droplets and polymeric matrix are constant during the shear deformation. After that the determination of dependence of geometric parameters variation upon tangential force remains only a mathematical problem.

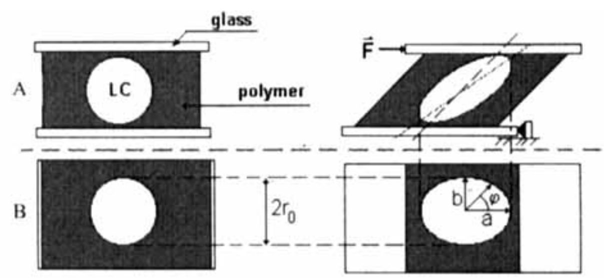

FIGURE 1. A deformation of spherical shape droplets to ellipsoid shape by an action of tangential force. A – side view, B- top view.

Usually thickness of real PDLC films is tens of microns and an area is a few square centimetres, so we may suppose that the length of the short axis of the formed LC droplet ellipsoid doesn't change perpendicular to the shear deformation. In the deformed PDLC structure the small semiaxis b of droplet ellipsoid remains approximately equal to the start radius r_o=0.127μm of the droplet. The transparency of such shear oriented PDLC film structures was investigated by linearly polarized laser beam at λ=0.6328μm. The sample was rotated along the axis parallel to an incident laser beam. The experimental angular light transmission a range φ = 0°- 360° trough shear deformed PDLC structure for linearly polarized light are plotted by circles in Figure2.

Striving to determine what a contribution could have an orientation of LC molecules along the deformation direction in droplets we change the average refractive index $\bar{n}$ to n_e and n_o in equations (11, 12). After that a variable refractive index n(φ) appears instead of $\bar{n}$ in equation (8)

$$n^2(\varphi) = \frac{n_e^2\ n_o^2}{n_o^2 \cos^2 \varphi + n_e^2 \sin \varphi} \tag{15}$$

In this case, other conditions mentioned above are the same; the resulting transparency is presented in Figure 2. by a dotted line.

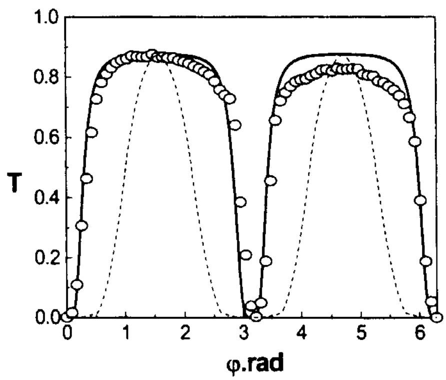

FIGURE 2. The transparency dependence upon sample rotation angle. Plotted full line - calculated values, circles – experimental values. Dotted line correspond to molecules oriented along deformation direction.

The calculation results are represented by a full line. The next experimental values were used for calculations: T_{min}=0.0005;

T_{max}=0.875; λ = 0.6328 μm; β = 0.00625; r_o= b = 0.127μm; d = 20 μm; a = 0.349μm n_e = 1.687; n_p = 1.526; n_o = 1.5314; V_{LC} = 0.32.

CONCLUSIONS

The calculated and experimentally determined PDLC film transparency dependence upon incident linearly polarized light is in good agreement. The agreement between the experimental measurements and the crude mathematical calculation was the best fit when an average refractive index $\bar{n}$ of LC droplets was used and such model could be used for practical purpose. From the calculated values and experimental results follow that the polarization features of the shear deformed PDLC structure are significant conditioned by the droplets shape.

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