JETP Letters, Vol. 71, No. 12, 2000, pp. 486–488. Translated from Pis'ma v Zhurnal Éksperimental'noĭ i Teoreticheskoĭ Fiziki, Vol. 71, No. 12, 2000, pp. 710–713.
Original Russian Text Copyright © 2000 by Konkolovich, Presnyakov, Zyryanov, Loĭko, Shabanov.

Interference Quenching of Light Transmitted through a Monolayer Film of Polymer-Dispersed Nematic Liquid Crystal

A. V. Konkolovich*, V. V. Presnyakov, V. Ya. Zyryanov**, V. A. Loĭko*, and V. F. Shabanov****

** Stepanov Institute of Physics, Belarussian Academy of Sciences, Minsk, 220072 Belarus*
e-mail: sasha@iph.krasn.ru; loiko@dragon.bas-net.by
*** Institute of Physics, Siberian Division, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia*
Received April 28, 2000

A theoretical study of light transmission through a polymer with a monolayer ensemble of bipolar nematic droplets under applied electric film is performed. The possibility of interference quenching of monochromatic coherent light directly transmitted through the film is predicted theoretically and realized in the experiment.
© 2000 MAIK "Nauka/Interperiodica".

PACS numbers: 78.66.-w; 61.30.-v; 78.20.Bh

The propagation of light in close-packed dispersive media is accompanied by interference phenomena, which should be taken into account in determining the characteristics of the transmitted and scattered light [1]. Theoretical studies of the scattering of coherent monochromatic light by a monolayer [1–3] revealed the possibility of interference quenching of the regular component of directly transmitted light. For the experimental realization of this effect, it is necessary that the parameters of the medium satisfy a number of strict requirements imposed on the size and shape of the scattering particles, their refractive index, and their concentration. The use of monolayer films of polymer-dispersed liquid crystals (PDLC) can simplify the solution of this problem, because one of the parameters of such films (the refractive index) can be varied by applying an electric field. This paper presents theoretical analysis and experimental study of the interference quenching of light transmitted through a monolayer PDLC film with a uniaxially ordered ensemble of bipolar nematic droplets in an external electric field.

For the theoretical analysis, we use the following approximations. The nematic droplets have the form of ellipsoids of revolution flattened in the film plane. The droplets are arranged in the polymer film in such a way that their centers lie in a single plane (a monolayer). The orientation ordering of the director inside the nematic droplets has a bipolar configuration with rigidly fixed poles [4–6]. The symmetry axes of all droplets of the ensemble are oriented in one direction in the layer plane. An electric field applied normally to the layer affects the director configuration in the droplets, leading to changes in their light-scattering properties. We will study the dependence of the transmittance $T = I_t/I_0$ (where I_t and I_0 are the transmitted and incident light intensities, respectively) on the voltage applied to the layer for coherently scattered light in the case of film illumination by normally incident, linearly polarized light with the polarization along the direction of the droplet symmetry axes.

The coherent transmittance T of a monolayer of isotropic particles has the form [1]

$$T = 1 - Q\eta + \frac{Q^2 L}{2}\eta^2, \qquad (1)$$

where Q is the extinction efficiency factor; the parameter L is determined by the amplitude of the scattering function at zero scattering angle; and η is the monolayer filling coefficient (the area fraction of droplets) equal to the ratio of the total area of the projections of all particles (droplets in the case of a PDLC monolayer) onto the monolayer plane to the area over which they are distributed. For a PDLC monolayer characterized by an optical anisotropy of LC droplets, Eq. (1) is retained but the values of Q and L are different in each specific case and determined by the size and shape of the droplets, as well as by their internal structure, depending on the control voltage.

For bipolar nematic droplets with rigidly fixed poles, the refractive index of the extraordinary wave n_e is a function of the control voltage U, and it is calculated according to the procedure proposed in [5, 6]. For the case of incident light with an electric vector oriented along the symmetry axes of the droplets, the anomalous diffraction approach yields the following relationships for the parameters Q and L of a monolayer with a gamma-distribution of droplets in size:

$$Q = 2\mathrm{Re}K, \tag{2}$$

$$Q^2L/2 = \mathrm{Re}K^2 + \mathrm{Im}K^2. \tag{3}$$

Here, the mean values of the real and imaginary parts, ReK and ImK, of the Hulst function K [7] are determined by the expressions

$$\mathrm{Re}K = 1 + B_e\Bigg[1 - \frac{C_e}{D_e} \times \cos\left((\mu+2)\arctan\frac{\nu_m^e}{\mu} - \arctan\frac{\nu_m^e}{\mu}(\mu+2)\right)\Bigg],$$

$$\mathrm{Im}K = \frac{B_eC_e}{D_e} \times \sin\left((\mu+2)\arctan\frac{\nu_m^e}{\mu} - \arctan\frac{\nu_m^e}{\mu}(\mu+2)\right), \tag{4}$$

where

$$B_e = \frac{2\mu^2}{(\nu_m^e)^2(\mu+1)(\mu+2)},$$

$$C_e = \left(1 + \frac{(\nu_m^e)^2(\mu+2)^2}{\mu^2}\right)^{1/2}, \quad D_e = \left(1 + \frac{(\nu_m^e)^2}{\mu^2}\right)^{\mu+2},$$

μ is the parameter of the gamma distribution,

$$\nu_m^e = \frac{2\pi\bar{c}n_p}{\lambda}(n_e(U)/n_p - 1), \tag{5}$$

n_p is the refractive index of the polymer, λ is the wavelength of the incident light, and $\bar{c}$ is the mean size of the LC droplets along the normal to the layer.

Theoretical estimates show that, for a PDLC monolayer with a mean droplet size of 12 μm and a variation coefficient of 0.2, interference quenching for a wave with $\lambda = 0.633$ μm occurs when the filling coefficient is $\eta = 0.7$ and the refractive indices are $n_p = 1.52$ and $n_e(U) = 1.56$.

For the experimental studies, we prepared samples of a polyvinylbutyral-dispersed 5CB nematic liquid crystal. The parameters of these samples were close to the calculated values necessary for interference quenching to occur. The liquid crystal was dispersed in the polymer according to the SIPS technique [8]. The uniaxial orientation of the ensemble of nematic droplets was achieved by means of uniaxial tension of the composite film [4]. The thickness of the films studied in the experiment was 16 μm. Figure 1 shows the micrograph of a sample area; the micrograph was obtained with the use of crossed polarizers. The filling coefficient was $\eta = 0.7$. The droplet size $\bar{c}$ varied between 10 and 14 μm with a mean value of 12 μm. The refractive index of the polymer matrix was $n_p = 1.52$. The refractive index of the 5CB liquid crystal was $n_o = 1.53$ for the ordinary wave, and, for the extraordinary wave with the electric vector oriented along the director of the nematic, it was $n_e(\max) = 1.717$ (the values are presented for $\lambda = 0.633$ μm [5, 6]).

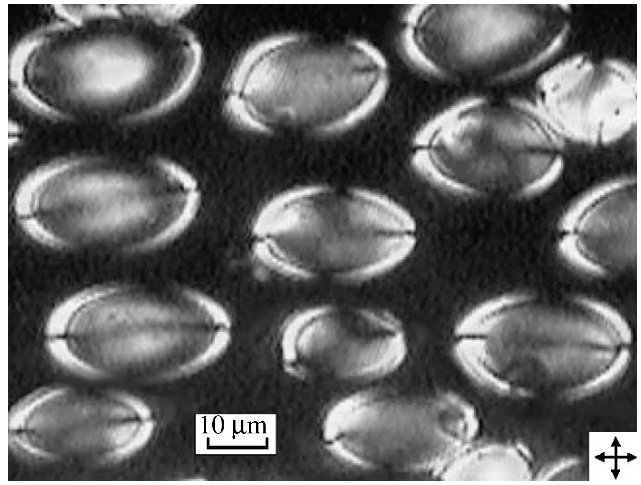

Fig. 1. Micrograph of a PDLC film; the image is obtained by using crossed polarizers whose orientation is shown by the arrows.

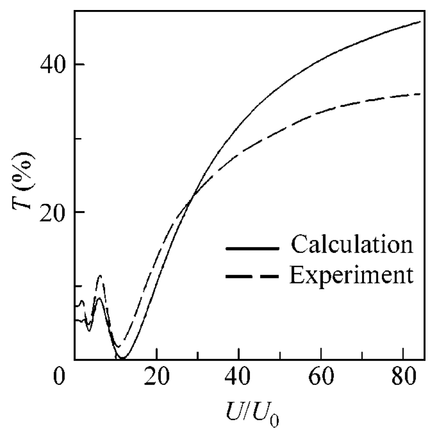

Fig. 2. Calculated and experimental dependences of the transmittance of a PDLC film on the control voltage normalized to the threshold value.

The source of radiation was a He–Ne laser with $\lambda = 0.633$ μm. The intensity of light transmitted through the sample and a circular aperture of diameter 1 mm placed at a distance of 143 cm from the sample was measured by a photodiode operating in a linear mode. The dependence of the intensity of transmitted light on the voltage applied to the sample was recorded by an X–Y plotter.

Figure 2 shows the calculated and measured values of the transmittance of the sample under study versus the control voltage normalized to the threshold value. The oscillatory behavior of the dependence is caused by the oscillations of the extinction efficiency factor Q

as a function of the control voltage. The number of oscillations is determined by the droplet size. One can see that the theoretical and experimental data are in good qualitative agreement.

We note that the minimum observed in the calculated dependence near $U/U_0 = 11.7$ occurs at $QL\eta = 1$ (see Eq. (1)). If, in addition, we have $L = 0.5$, the value of the transmittance T becomes zero; i.e., interference quenching of the directly transmitted light takes place. For the experimental dependence, the minimum value of the transmittance $T = 1.7\%$ is observed at $U/U_0 = 10.8$. The difference between the experimental and theoretical data is caused by the following factors. First, in calculating the filling coefficient of the film that is necessary for quenching to occur, one must proceed from the real droplet size distribution. Second, in a real ensemble of bipolar droplets, the uniaxial orientation of the symmetry axes of droplets is imperfect. In the case of even a slight deviation of the droplet symmetry axes from the preferred direction, the transmitted light will contain an ordinary component for which the conditions of interference quenching are not valid.

Thus, by theoretically analyzing the interference features of the electro-optical response of dispersed nematic liquid crystal monolayers, we arrived at the conclusion that, in PDLC films, quenching of the directly transmitted coherent monochromatic light is possible. According to the theoretical estimates, special samples were prepared on the basis of PDLC monolayers. For these samples, we observed an interference quenching effect that was characterized by a minimum coherent transmittance of 1.7%.

In practical applications, PDLC films with a multilayer droplet arrangement are more common [8]. In this case, one obtains a high contrast due to the multiple scattering of light. Such films are fairly thick (20–30 μm) and hence have a high control voltage. The studies described above open up prospects for the development of thin PDLC monolayers with a high contrast and a low-voltage control.

This work was supported in part by the Ministry of Science and the Ministry of Education of the Russian Federation, by the INTAS (grant no. 97-1923), and by the Krasnoyarsk Science Foundation. The theoretical studies were supported in part by the INCO-Copernicus program (contract no. IC15-CT98-CT98-0806).

REFERENCES

1. A. P. Ivanov, V. A. Loĭko, and V. P. Dik, *Light Propagation in Close-Packed Dispersive Media* (Nauka i Tekhnika, Minsk, 1988).
2. V. A. Loĭko and A. V. Konkolovich, Mol. Cryst. Liq. Cryst. **303**, 41 (1997).
3. V. A. Loĭko and A. V. Konkolovich, Mol. Cryst. Liq. Cryst. **320**, 337 (1998).
4. V. Ya. Zyryanov, V. V. Presnyakov, and V. F. Shabanov, Pis'ma Zh. Tekh. Fiz. **22** (14), 22 (1996) [Tech. Phys. Lett. **22**, 563 (1996)].
5. A. V. Shabanov, V. V. Presnyakov, V. Ya. Zyryanov, and S. Ya. Vetrov, Pis'ma Zh. Éksp. Teor. Fiz. **67**, 696 (1998) [JETP Lett. **67**, 733 (1998)].
6. A. V. Shabanov, V. V. Presnyakov, V. Ya. Zyryanov, and S. Ya. Vetrov, Mol. Cryst. Liq. Cryst. **321**, 245 (1998).
7. H. C. van de Hulst, *Light Scattering by Small Particles* (Wiley, New York, 1957; Inostrannaya Literatura, Moscow, 1961).
8. G. M. Zharkova and A. S. Sonin, *Liquid-Crystal Composites* (Nauka, Novosibirsk, 1994).

Translated by E. Golyamina