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# Transmittance and Spatial Optical Noise of Polymer Dispersed Liquid Crystal Layers

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# TRANSMITTANCE AND SPATIAL OPTICAL NOISE OF POLYMER DISPERSED LIQUID CRYSTAL LAYERS

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Abstract On the base of the optical scattering methods, the transmittance and spatial noise spectrum of polymer dispersed liquid crystal layers are etermined. We take into account optical properties of liquid crystal droplets, spatial number fluctuations of the droplets, and droplets topological ordering.



## INTRODUCTION

Number fluctuation of liquid crystal (LC) droplets and fluctuations in their properties which take place in polymer dispersed liquid crystal (PDLC) layers lead to optical noise of such systems designed for optical image reproduction. A model which takes into account electrooptical properties of LC droplets and their concentration is proposed here. It allows one to analyze transmittance and noise properties of PDLC layers.The relations for the transmittance and noise spectrum is derived on the base of the simulation of a thin layer by two-demensional medium in the form of a stochastic amplitude-phase screen with transmission function of an equivalent screen identified as a microdroplet.

## COHERENT TRANSMITTANCE AND WIENER SPECTRUM OF A THIN PDLC LAYER

Imagine a PDLC layer as a set of thin layers. Within every thin layer, there is no overlapping droplets projections on the layer plane.Consider transmittance of a thin layer on the base of the stochastic amplitude - phase screen (APS) model [1].

Let a thin layer (monolayer) be illuminated normally to its surface by linearly-polarized plane wave. Introduce transmittance functions of the equivalent screens which are identified with LC droplets, for VV and VH components of the scattered light [2], i.e. of light polarized parallel and perpendicular polarization plane of the incident wave correspondingly. Then we find coherent transmittance $T_c$ ( $T_c$ describes light flux passing through the layer without deflection [3]) by averaging local values of the amplitude transmittance for VV and VH components, summing up the squares of the magnitudes of their mean values, and integrating over all values of polarization angle $\alpha$. The latter gives the of polarization vector direction of incident light relative to the main plane [4].

For spherical monodisperse LC droplets, we have

$$T_c = 1 - Q\eta + \frac{Q^2 L}{2}\eta^2, \tag{1}$$

where

$$Q = \frac{2}{\pi\rho^2}\int_0^{2\pi} \mathrm{Re} f_{vv}(0) d\alpha, \tag{2}$$

$$L = \frac{\pi}{2}\frac{\int_0^{2\pi}(|f_{vv}(0)|^2 + |f_{vh}(0)|^2) d\alpha}{(\int_0^{2\pi}\mathrm{Re} f_{vv}(0) d\alpha)^2}. \tag{3}$$

$\eta$ is the filling coefficient of a thin layer being equal to the ratio of the projection area of all droplets on the plane of the layer to the area where they are located, $f_{vv}(0)$, $f_{vh}(0)$ are the VV and VH components of the vector amplitude function, determined through elements of the scattering matrix [4], $\rho$ is the size parameter ( $\rho = \pi d / \lambda$ , $d$ is the droplet diameter, $\lambda$ is the wavelength). It follows from Eq. (1) that $T_c$ is a monotonically decreasing function with $\eta$ when droplets parameter $QL < 1/\eta_{\max}$ , where $\eta_{\max}$ is the maximum value of the filling coefficient (for monodisperse spherical droplets $\eta_{\max} = 0.907$ [3]). Dependence of $T_c$ on $\eta$ has a minimum when $QL > 1/\eta_{\max}$. The minimum value of the coherent transmittance is $T_{\min} = 1 - 0.5/L$ at the filling coefficient $\eta_{\min} = (QL)^{-1}$.

Determine spatial noise (Wiener) spectrum on the base of the 2-d finitary Fourier transform of the local fluctuations of the coherent transmittance [1]. Taking into account the rectangular type of the transmittance function of the equivalent screens for VV and VH components [2], we will find for the layer with spherical droplets:

$$n(0) = s\eta \frac{(1-\eta)^3}{1+\eta} Q^2 (1 - Q L\eta)^2, \tag{4}$$

$$n_n(z) = \left[\frac{2J_1(z)}{z}\right]^2 \frac{1 - 8\eta \int_0^\infty (1 - W(x)) J_0(2zx) x dx}{1 - 8\eta \int_0^\infty (1 - W(x)) x dx}. \tag{5}$$

Wiener spectrum $n(\nu)$ is determined as a product of $n(0)$ and $n_n(z)$ which are the values of the spectrum on zero spatial frequency ($\nu = 0$) and normalized spectrum correspondingly.

In last expressions $z = \pi \nu d$, $\nu$ is the magnitute of the spatial frequency vector, $s = \pi d^2 / 4$, $J_0$ and $J_1$ are the cylindrical zero- and first-order Bessel's functions of the first kind, respectively, $W$ is the radial distribution function of droplets [5]. Function $W$ was determined on the base of the solution of the Ornstein-Zernike equation under Percus-Yevick's approximation for "hard" spherical droplets.

Pay attention that parameters $Q$ and $L$ include electrooptical properties droplets in the obtained expressions. For taking into account reirradiation between droplets in the frame of the discussed model we have to determine effective scattering matrices including multiple scattering and to find $Q$ and $L$ values on their base.Under the single scattering approximation, Q and L values are calculated via scattering matrices of a single droplet.

## RESULTS

Consider a layer with LC nematic droplets when the directors are distributed uniformly. Concentrate our attention on the layers enabling one to use the single scattering approximation. Then for relatively large droplets, we have under the anomalous diffraction approximation [6]

$$Q = 2\,\mathrm{Re}(K(iv_e) + K(iv_0)), \tag{6}$$

$$L = \frac{|K(iv_e)|^2 + |K(iv_0)|^2}{(\mathrm{Re}\,K(iv_e) + \mathrm{Re}\,K(iv_0))^2}. \tag{7}$$

Here $K$ is the van de Hulst's function [7], $v_e = 2\rho(n_e(\theta)/n_m - 1)$, $v_0 = 2\rho(n_0/n_m - 1)$, $n_e(\theta) = (\cos^2\theta/n_0^{\,2} + \sin^2\theta/n_e^{\,2})^{-1/2}$, $n_0, n_e, n_m$ -are the refractive indices of ordinary, extraordinary waves and binding polymeric medium, correspondingly, $\theta$ is the angle between the wave vector of the incident wave and droplet director.

Figs. 1, 2, 3, show the calculations for the planar structure of the directors in the layer ($\theta = 90°$) at $n_0 = 1.52, n_e = 1.7, n_m = 1.55$. Fig.1 illustrates vividly that there are above mentioned extrema of $T_c = T_c(\eta)$ at the filling coefficient $\eta \geq 0.56$ and size parameter $5 < \rho < 150$. Transmittance $T_c$ is a monotonous function of the filling coefficient $\eta$ when $\rho > 150$. For large droplets with $\rho \to \infty$, parameters $Q = 2$, $L = 0.5$ and the value of $T_c = (1-\eta)^2$.

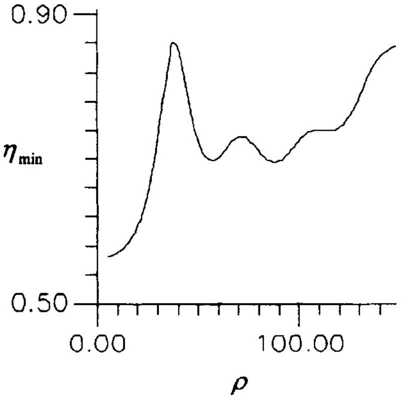


FIGURE 1 Dependence of $\eta_{min}$ on size parameter, $\rho$.

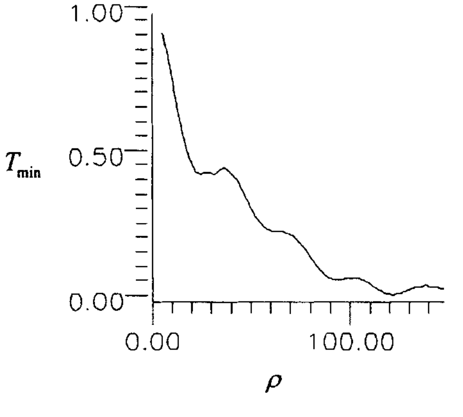


FIGURE 2 Dependence of $T_{min}$ on size parameter, $\rho$.

The dependence of the minimal transmittance value $T_{\min}$ on size parameter $\rho$ is shown in Fig.2. It follows from Eq.(1) and Fig.2 that the increase in the transparency at all concentrations corresponds to decrease $\rho$.

The noise level at zero spatial frequency $n(0)/s$ is shown in Fig. 3. It is possible to get two maxima and a zero minimum. The latter takes place at $\eta_{\min} = 1/QL$ (See Eq.4). The dependence of such kind is for droplets when $QL > 1/\eta_{\max}$. This condition coincides with that for the function $T_c = T_c(\eta)$ has the minimum. There is only a single maximum if $QL < 1/\eta_{\max}$.



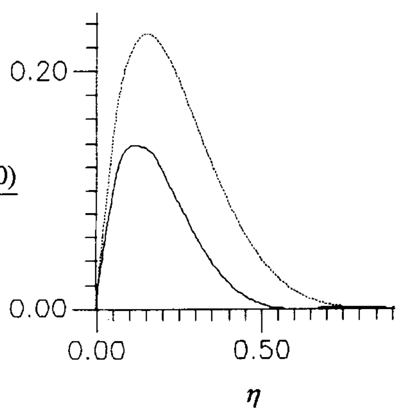


FIGURE 3 Dependence of $n(0)/s$ on filling coefficient, $\eta$; solid line - $\rho = 20$; dashed line - $\rho \to \infty$.

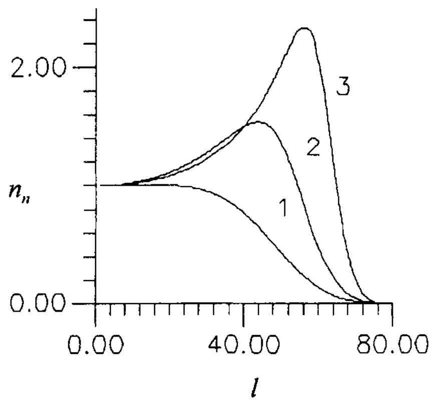


FIGURE 4 Dependence of $n_n$ on dimensionless frequency, $l$; 1 - $\eta = 0.2$; 2 - 0.4; 3 - 0.6.

The normalized spatial noise spectrum $n_n(\nu) = n(\nu)/n(o)$ is shown in Fig. 4. Here the dimensionless frequency $l$ and spatial frequency $\nu$ in $mm^{-1}$ relate by $\nu = 50l/\pi d$, where $d$ is in $\mu m$. The dependence of $n_n = n_n(\nu)$ decreases monotonically with the spatial frequency at concentrations corresponding to filling coefficient $\eta \le 0.2$. At $\eta \ge 0.2$, the spectrum has a maximum increasing with filling coefficient. The more $\eta$ the narrower this maximum.

## CONCLUSIONS

Obtained results show new ways for the optimization of the transmittance and optical noise of thin PDLC layers not only by electrooptical properties of LC droplets but also by their concentration. They can be useful in designing the models for quality characteristics estimation of real PDLC layers. The proposed model together with the estimation of the transmittance for coherent light component enables us to investigate diffuse (incoherent) transmittance and noise properties at arbitrary scattering angles with taking into account:

(i) director's arrangement of droplets for different types of LCs under the controlling field and without it;

(ii) polydispersity of droplets;

(iii) multiple scattering of light in a layer.

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