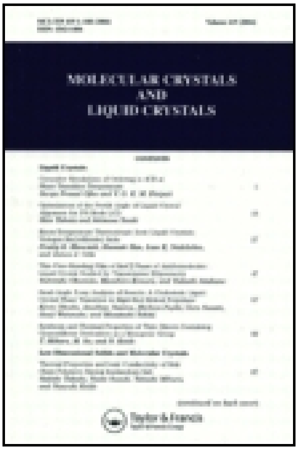

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Static Spatial Optical Noise Spectrum of Surface Liquid Crystal Droplets Film

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Static Spatial Optical Noise Spectrum of Surface Liquid Crystal Droplets Film

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The equation for spectral noise power density of surface liquid crystal droplets (SLCD) films for coherent transmitted light has been obtained. Monodisperse hemi-sphere-shaped droplets of a bistable ferroelectric liquid crystal (LC) with homogeneous planar orientation of directors are considered. Assuming nonoverlapping discs, we analyze the influence of spatial correlation in the arrangement of droplets on the spectral noise and the signal-noise ratio.

Keywords: ferroelectric; transmittance; noise; spectrum

INTRODUCTION

In the last few years, surface liquid crystal droplets (SLCD) films have been the subject of much investigation.[1,2] By virtue of their small thickness, control voltage for such films is considerably lower and a high contrast can be obtained due to the realization of the interference quenching effect.[3] However, when SLCD films are used in display systems, analysis of spatial optical noise caused by the discrete-inhomogeneous structure of the film is required. Among the factors determining the nature of noise are: spatial fluctuations of the number of liquid crystal droplets within the pixel area; polydispersity of droplets and disorientation of their optical axes.

The most complete characteristic of noise is the spatial-frequency Wiener's spectrum[4,5] which permits determining the noise dispersion, the signal to noise ratio (SNR), and other noise characteristics.

BASIC EQUATIONS FOR THE WIENER SPECTRUM

By definition, the Wiener spectrum $n(\underline{v})$ as a function of the spatial frequency vector $\underline{v}$ is[4,5]

$$n(\underline{v}) = \lim_{A\to\infty} \frac{1}{A} \langle \left| TF_A\{t(\underline{x})\} \right|^2 \rangle, \tag{1}$$

where $TF_A\{t(\underline{x})\}$ is a two-dimensional Fourier transform of the function $t(\underline{x})$ describing the spatial fluctuations of the quantity being investigated at point $\underline{x}$ on the SLCD film surface, A is the portion of the film surface where averaging is made and the brackets $\langle\rangle$ denote the ensemble averaging.

Based on the methods for forming functions of fluctuations from the point of view of the amplitude-phase screen (APS) model,[4] separating preliminarily the VV- and VH- components in directly transmitted light,[6] for the hemi-sphere shaped droplets equal in size and with their directors aligned in the plane of the film we find:

$$n(z) = \sigma\eta Q^2 (1 - QL\eta)^2 \left[\frac{2J_1(z)}{z}\right]^2 S(z). \tag{2}$$

Here the structure factor

$$S(z) = 1 - 8\eta \int_0^{\infty} (1 - W(u)) J_0(2zu) u du , \tag{3}$$

where $\sigma = \pi c^2 , z = 2\pi \nu c, \nu$ is the modulus of the spatial frequency vector; c is the radius of droplets; W is the radial distribution function;[7] J_0 and J_1 are, respectively the zeroth- and the first-order cylindrical Bessel function of the first kind; η is the filling coefficient[3,4,8]. The extinction efficiency factor Q and the parameter L in Equation (2) are

$$Q = \frac{4}{k^2 c^2} \operatorname{Re} f_{+,-}^{VV}(0) , \tag{4}$$

$$L = \frac{1}{2}\left(1 + \frac{\operatorname{Im}^2 f_{+,-}^{VV}(0)}{\operatorname{Re}^2 f_{+,-}^{VV}(0)}\right)\left(1 + \frac{\left|f_{+,-}^{VH}(0)\right|^2}{\left|f_{+,-}^{VV}(0)\right|^2}\right), \tag{5}$$

$$f_{+,-}^{VV}(0) = k^2 c^2 \left\{ K(iv_e) \cos^2 \alpha^{+,-} + K(iv_o) \sin^2 \alpha^{+,-} \right\}, \tag{6}$$

$$f_{+,-}^{VH}(0) = \frac{k^2 c^2}{2} \left\{ K(iv_o) - K(iv_e) \right\} \sin 2\alpha^{+,-} , \tag{7}$$

where $k = 2\pi / \lambda, \lambda$ is the wavelength of incident light in the polymer; K is the Hulst function;[8] $v_e = kc\left(\frac{n_e}{n_p} - 1\right)$; $v_o = kc\left(\frac{n_o}{n_p} - 1\right)$; n_o, n_e, n_p are the ordinary and the extraordinary refractive index of LC and the refractive indices of the binding polymer, respectively.

Equations (6), (7) take into account that under the action of an external field the director of the droplet with a bistable ferroelectric LC takes on two stable states:[3,8] the $\underline{d^+}$ - state and the $\underline{d^-}$ - state. If in the $\underline{d^+}$ - state the incident wave is polarized along the droplet director, then in Equations (6), (7) $\alpha^+ = 0$ and $\alpha^- = 2\varphi_d$, where φ_d is the tilt angle.

The noise dispersion $D^2_{T_c}$ is related to the spectrum value at zero spatial frequency $n(0)$ by the relation:[5]

$$n(0) = D^2_{T_c} A\,. \tag{8}$$

On the other hand, from Equation (2) we have:

$$n(0) = \sigma\eta Q^2 (1 - QL\eta)^2 S(0)\,, \tag{9}$$

$S(0)$ is the value of the structural factor at $\nu = 0$. Below we analyze the signal to noise ratio, SNR (T_c / D_{T_c}), therefore we write here the expression for the coherent transmission coefficient of the film:

$$T_c = 1 - Q\eta + \frac{Q^2 L}{2}\eta^2\,, \tag{10}$$

in which Q and L are changed, when the director goes from the $\underline{d^+}$ - to the $\underline{d^-}$ - state, in accordance with Equations (4)-(7). Comparing Equations (8)-(10), we see that

$$T_c / D_{T_c} = \Upsilon \sqrt{\frac{A}{\sigma}}\,, \tag{11}$$

where

$$Y = \frac{1 - Q\eta + \dfrac{Q^2 L}{2}\eta^2}{\sqrt{\eta Q^2 (1 - QL\eta)^2 S(0)}}. \tag{12}$$

The parameter Y is a convenient quantity which is independent of the pixel area A and determines all the characteristic features of SNR behavior depending on the concentration of droplets and their electrooptical properties.

RESULTS

Figure 1 shows the normalized spectrum $n_n = n(z)/n(0)$ (see Equations (2), (9)). The characteristic feature of noise is the appearance

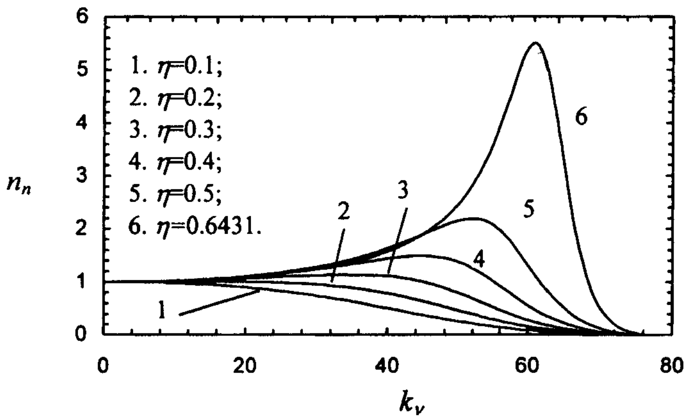

FIGURE 1 Normalized Wiener spectrum of SLCD films at various filling coefficients.

of a maximum at droplet concentration values $\eta > 0.2$. The maximum increases with increasing η; to each value of k_ν there corresponds a spatial frequency $\nu = 25k_\nu / (\pi c)$ given in mm^{-1} with droplet sizes c given in μm.

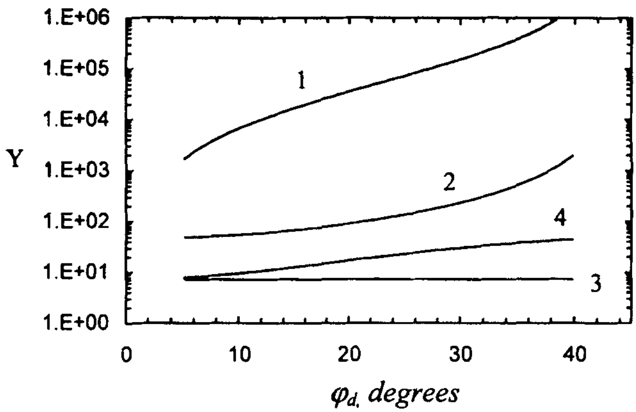

FIGURE 2 Parameter Y versus the tilt angle φ_d
$\eta = \eta_0 = 0.6431$; $n_o = 1.524$; $n_e = 1.722$.
1. $n_p = 1.524$; $kc = kc_0 = 34.59$;
2. $n_p = 1.524$; $kc = 10.91$;
3. $n_p = 1.601$; $kc = 59.65$;
4. $n_p = 1.589$; $kc = 34.51$.

In calculations, we used the analytical expression for the structure factor of Equation (3) obtained in the Reference[9] for a system of nonoverlapping round discs located on a plane, which gives a good agreement with exact calculations at $\eta \le 0.7$.

Let us analyze parameter Y as a function of φ_d in some typical situations where the director is switched from the $\underline{d}^+$ - to the $\underline{d}^-$ - state. Figure 2 shows four characteristic curves for Y which correspond to four variants of switch of the coherent transmission coefficient: (i) the quenching effect in the $\underline{d}^+$ - state, $T_c^+ = 0$ and the total transparency in the $\underline{d}^-$ - state, $T_c^- = 1$ (curve 1); (ii) $T_c^+ \neq 0$ and $T_c^- = 1$ (curve 2); (iii) $T_c^+ = 0$ and $T_c^- \neq 1$ (curve 3); (iv) $T_c^+ \neq 0$ and $T_c^- \neq 1$ (curve 4). The last three variants are achieved by mismatch of the quenching conditions and (or) SLCD film transparency in the $\underline{d}^+$ - and the $\underline{d}^-$ - state (see Ref. 3,8) which we write here: $\eta = \eta_0 = 0.6431$; $kc_0 = 4.4934 \Big/ \left(\frac{n_e}{n_p} - 1 \right)$; $n_p = n_o$; $\varphi_d = 45^\circ$.

CONCLUSION

The analysis of the noise characteristics accounts for the influence of fluctuations in the number of droplets and space correlation in their arrangement for a monodisperse system. The equation for the Wiener spectrum (Equation (2)) permits analytical account of other factors determining the nature of noise as well. In particular, the disorientation of the droplets optical axes will enter into the obtained expressions through the mean values of the parameters Q and L.

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