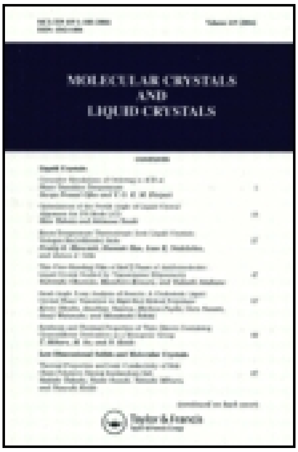

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Extinction of Light by PDLC Film with Oriented Ellipsoidal Nematic Droplets: Theoretical Study

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Extinction of Light by PDLC Film with Oriented Ellipsoidal Nematic Droplets: Theoretical Study

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Extinction efficiency factor of bipolar oblate and prolate ellipsoidal droplets in discrete dipole approximation has been investigated. It has been shown that maximum contrast ratio is achieved for a film with elongated ellipsoidal droplets aligned normally to the film surface.

Keywords: liquid crystal dispersions; contrast ratio.

INTRODUCTION

In conventional polymer dispersed liquid crystal (PDLC) films, droplets are deformed into an ellipsoidal shape flattened along the normal to the film surface.[1] There are PDLC films with extended ellipsoidal droplets whose axes are aligned parallel to the film surface.[2-4] Ellipsoidal droplets are formed in holographic PDLC films too.[5] The elongated cavities are formed in channel structures of ultraviolet laser curable PDLC films.[6] In nematic colloidal dispersions, electrically driven elongation of suspended droplets is implemented.[7]

In most cases, considered in the literature, theoretical analysis of scattering and extinction by a single liquid crystal (LC) droplet is based on the model of a spherical droplet.[1] Here we consider the model of scattering, which is applicable for a LC droplet of any shape and any director configuration. Calculations of extinction efficiency factors and analysis of contrast properties of composite films formed by oriented ellipsoidal oblate and prolate bipolar nematic droplets are presented in this paper.

The discrete dipole approximation (DDA), which enable one to consider scattering and extinction of incident light by a droplet with any director field is used. The molecules are supposed to be oriented along elliptical lines lying on the surfaces of nested ellipsoids with common axis and vertices [1] (model of nested ellipsoids). In other words, the ellipsoids are tangent to each other in two vertex points.

EXTINCTION EFFICIENCY FACTOR

A thin film with oriented ellipsoidal nematic LC droplets is considered. Figure 1 illustrates the droplet orientation for two cases of droplet illumination, parallel and perpendicular to rotation axis b of an ellipsoid with different aspect ratios b/a. The axis b is perpendicular (top) and parallel (bottom) to the film surface. The droplet director is aligned normally ("OFF" state) and along ("ON" state) to wave vector $\vec{k}$ of the incident light.

The extinction efficiency factor[8] of droplets was calculated under the DDA.[9-11] In this approach the droplet is presented as a set of subparticles (dipoles), which are small as compared to the wavelength. These dipoles have optical properties of a bulk liquid crystal. Such a representation permits one, by an appropriate breakdown of the droplet, to get a result for droplets with practically any director configuration and shape.

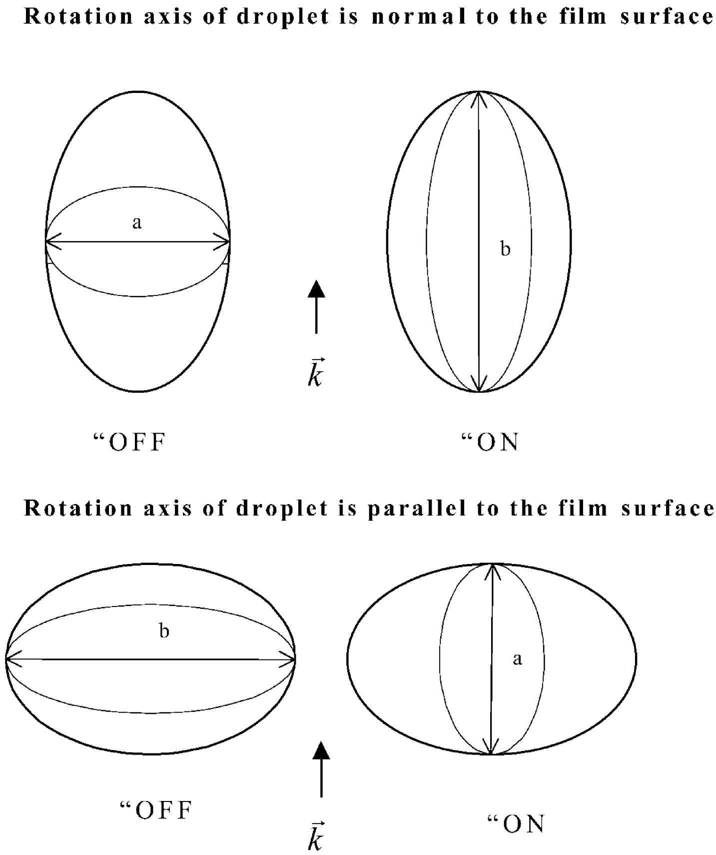

FIGURE 1. Schematic representation of the droplet orientation and illumination. Rotation axis *b* of the ellipsoid is perpendicular (top) and parallel (bottom) to the film surface; $\vec{k}$ is the wave vector; *a,b* are the droplet axes.

The main equations for the calculations are presented in our previous publication,[10] where the results for spherical LC droplets are given. We used the program DDSCAT (DDSCAT – Draine, Flatau, ftp://astro.princeton.edu/draine/scat/ddscat/ver5a) modified by us.

Extinction efficiency factors Q^{off} and Q^{on} in "OFF" and "ON" states are shown in Figures 2 and 3 as a function of size parameter $x=\pi d/\lambda$. Here d stands for the diameter of a droplet which has the same volume as the ellipsoid, λ is the wavelength in the polymer. In these Figures $n=n_e/n_p$ (n_e is the extraordinary refractive index, n_p is the refractive index of the polymer matrix). The ordinary refractive index is equal to that of the polymer matrix, $n_o=n_p$. One can see the difference in Q^{on} and Q^{off} for illumination parallel (Figure 2) and perpendicular (Figure 3) to the rotation axis of the ellipsoid. We only pay attention to that the position of the maximum of the dependence of Q^{off} on x shifts to smaller x values with increasing aspect ratio. With decreasing n_e/n_p, this maximum decreases too. In "ON" state the value of the maximum decreases and shifts to higher x values and can even disappear.

CONTRAST RATIO

We study sizes and orientations of droplets (parallel and perpendicular to the film surface) providing a maximal contrast at a fixed transparency of a film. Contrast ratio (CR) of a film is defined by the conventional way:

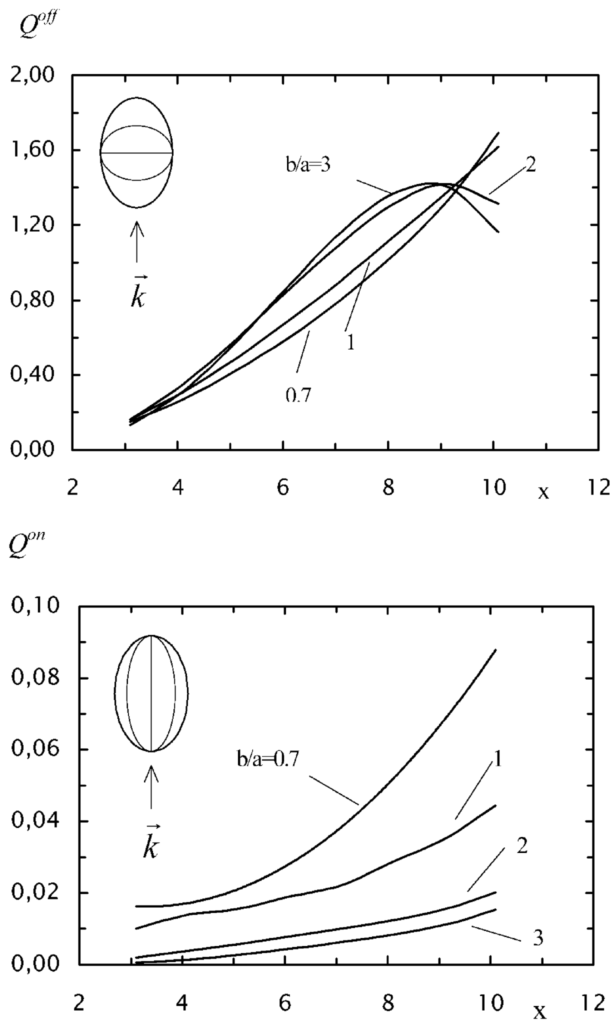

FIGURE 2. Dependence of Q^{off} (top) and Q^{on} (bottom) on x at n=1.15. The wave vector $\vec{k}$ is parallel to the rotation axis of the ellipsoid.

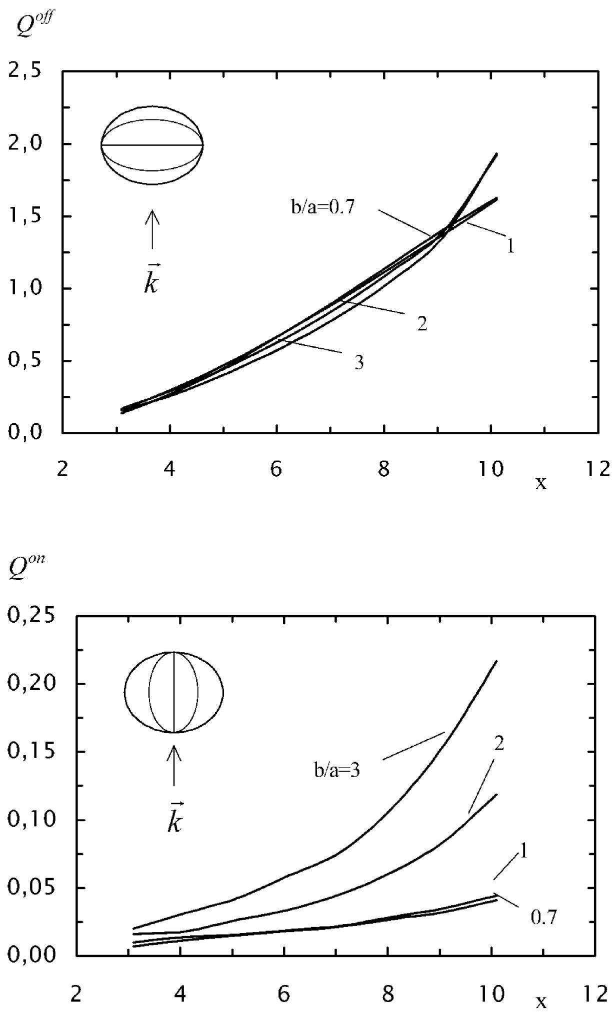

FIGURE 3. Dependence of Q^{off} (top) and Q^{on} (bottom) on x at n=1.15. The wave vector $\vec{k}$ is normal to the rotation axis of the ellipsoid.

$$CR = T^{on} / T^{off} . \quad (1)$$

Here T^{on} and T^{off} are transmittance values of a film in transparent ("ON") and opaque ("OFF") states, respectively.

For the directly transmitted light one can write:

$$T^{on} = \exp(-Q^{on}\eta) , \quad (2a)$$

$$T^{off} = \exp(-Q^{off}\eta) , \quad (2b)$$

where η is a parameter, which depends on droplets concentration, geometrical cross section of a droplet, and film thickness; Q^{on} and Q^{off} are the extinction efficiency factors of the droplet in "ON" and "OFF" states, respectively.

For the same size, shape, orientation, and concentration of droplets, the quantities Q^{on} and Q^{off} depend only on the droplet director structure. In such a case:

$$CR = \exp(-\eta[Q^{on} - Q^{off}]) . \quad (3)$$

To compare CR values of different films, we normalize their transmittances to the same magnitude, i.e. constant transmittance in "ON" state, $T^{on} = 1/e$, is assumed. In such a case $\eta = 1/Q^{on}$ and

$$Q^{off} / Q^{on} = \ln(CR) + 1 . \quad (4)$$

Hence it is possible to get qualitatively the CR behavior as a function of droplet size and shape from extinction efficiency factors of droplets in "OFF" and "ON" states. It is worthwhile to note that our numerical analysis can be directly used for PDLC films with dual frequency addressing.[12]

Figure 4 presents the calculations of Q^{off}/Q^{on} for prolate (top) and oblate (bottom) ellipsoidal droplets with $n=1.15$. Maximal contrast ratio can be seen to take place for extended droplets oriented normally to the surface. The numerical calculations have shown that, with aspect ratio increasing up to 10, the value of Q^{off}/Q^{on} is growing up. In the "OFF" state maximum value of Q^{off} occurs in the vicinity of parameter $x_m^{off} \approx 20$. In the "ON" state it shifts to the essentially larger sizes, and the value of Q^{on} grows monotonically up to x_m^{off}. Therefore maximum of the *CR*-*x* dependence is achieved at *x* values less than x_m^{off}.

CONCLUSION

Extinction efficiency factors for bipolar nematic droplets of ellipsoidal shape are numerically calculated. It is possible to get greater values of Q^{off}/Q^{on} at $x<2$ than in PDLC films with $x>2$ conventionally used for amplitude modulation.

It has been shown that the greatest values of the contrast ratio in the transmittance mode are achieved for elongated droplets aligned normally to the film surface. For aspect ratio more than two, it is possible to get more than five-fold increase in the contrast ratio as compared with spherical droplets.

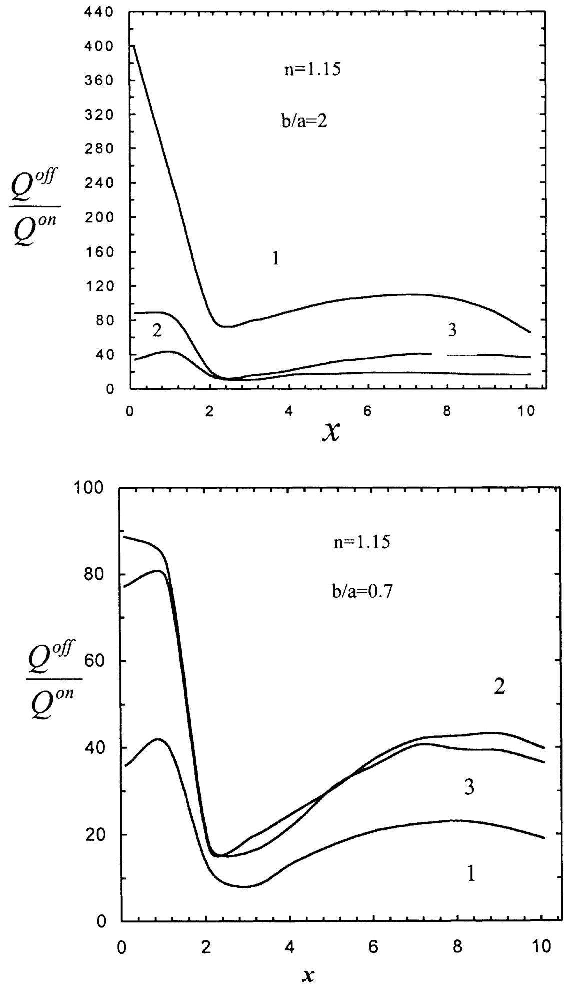

FIGURE 4. Dependence of Q^{off}/Q^{on} on x for prolate (top) and oblate (bottom) ellipsoids (curves 1 and 2) and sphere (3). Rotation axis b is parallel (1) and normal (2) to the film surface.

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