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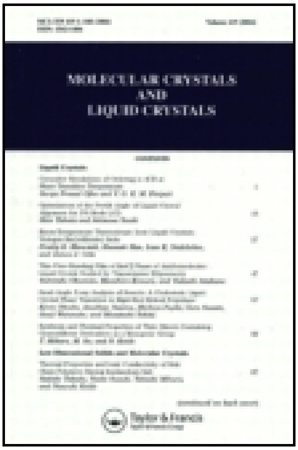

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Selective Reflection of Light from Aqueous Dispersions of Encapsulated Cholesteric Liquid Crystals

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The transmission of light through a layer of cholesteric liquid crystals (CLCs) encapsulated in a polymer and suspended in water is studied both theoretically and experimentally. The morphology of the capsules is considered alongside with spectral dependences of light transmission through a plane-parallel layer of aqueous CLCs dispersions.

Keywords: selective reflection; microcapsules

INTRODUCTION

The liquid crystals of the cholesteric type are widely used as temperature indicators. Their operational principle employs temperature dependence of the wavelength of light selectively reflected from the CLCs layer.

Encapsulation of an LC in a polymeric matrix is often used in order to protect the LC from detrimental external influences. Depending on the applied encapsulation procedure, either film materials containing CLCs droplets embedded in a polymeric matrix (polymer dispersed, or pseudo-encapsulated CLCs) can be obtained, or, by adding a coacervation step during preparation, isolated CLCs microcapsules suspended in an isotropic medium[1]. The latter materials are of obvious practical interest, since they proved to be useful as temperature tracers for gasdynamic studies[2].

This paper presents both theoretical and experimental studies of the optical properties of a CLCs in the form of capsules suspended in water.

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MATERIALS AND EXPERIMENTAL PROCEDURE

In the paper, spectral characteristics of light transmission by a layer of CLCs microcapsules suspended in water is experimentally studied. The capsules were prepared using the CLCs microcapsulating method based on the phase separation procedure[3,4].

As the cholesteric, a LC mixture of cholesteryl pelargonate and cholesteryl valerate (50:50) was used. As the polymer matrix was used gelatin. The temperature range of the selective reflection of the prepared mixture was 32-35 °C. Samples were studied containg 2% of microcapsules suspended in water. The morphology of the prepared suspensions of capsules was studied using a TV microscope. The distribution of capsules over sizes can be fairly well described by gamma-distribution. The mean microcapsule diameter was found to be 15 microns.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The spectral transmission of light by the plane-parallel layer of the capsules suspended in water was measured on a single-beam "Specol-2000" spectrophotometer. The pitch of the cholesteric helix was varied by supplying heat to the plane-parallel cell containing the dispersion of the microcapsules. The spectrum of light transmission of the encapsulated CLCs is determined by processes of multiple reflection and transmission of light by polymeric boundaries of microcapsules, as well as by those of selective light transmission by the supermolecular CLCs texture inside a capsule. To separate out the selective component in the transmission spectra, the spectral characteristics of the dispersed microcapsules were recorded against their transmission spectra at a temperature of isotropic state of the encapsulated CLCs. In this manner, the spectrum determined solely by the CLCs texture in capsules was extracted (Fig.1). The intensity of the light having passed through the microcapsules was found to be smaller, and peaks broader, which is indicative of a certain degree of disordering of the molecules in capsules as compared to the planar texture of pure LCs. For an estimate of the alignment degree of the CLCs molecules in the capsules, the spectral order parameter S can be use, which represents the ratio between the semiwidths at half maximum of the transmission peaks exhibited by the sample under test and a quasi-homogeneous (with a symmetric peak) sample[5]. For the CLCs textures under study, the S factor was found to be 0.70. It is worth noting here for comparison purposes that the order parameter S for the planar texture amounts to 0.92, while that of pseudo-encapsulated films 0.78. The high order parameter at encapsulation provides an evidence for the realization in capsules of a tangent texture.

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THEORY

As the incident light passes through a plane-parallel layer of particles, its intensity decrease according to the following law[6]:

$$T = (I/Io)\ exp(-\alpha d)\ , \qquad (1)$$

where Io is the intensity of the insident light; I is the intensity of the transmitted light; d the layer thickness and α the attenuation factor given by the expression

$$\alpha = N \int_0^{\infty} Cext(R) f(R) dR\ , \qquad (2)$$

where N is the number of particles in a unit volume, $Cext(R)$ is the extinction cross section of a single particle of a radius R, and $f(R)$ the distribution function of capsules over sizes.

$$f(R) = (R^{\alpha}\ exp(-R/\beta))/(\Gamma(\alpha+1)\beta^{\alpha+1}), \qquad (3)$$

where $\alpha>-1$, $\beta>0$, $\Gamma(\alpha+1)$ is gamma-function, $\Gamma(n) = \int_0^{\infty} z^{n-1} exp(-z)dz$.

For non-absorbing particles, to which the capsules under study fall, *Cext=Csca*, where *Csca* is the scattering cross sections. Taking into account that the capsules

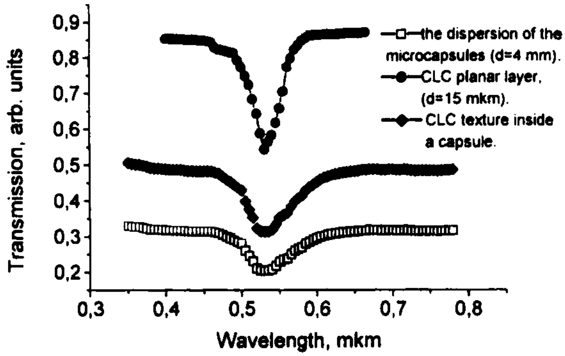

FIGURE 1 Experimental dependences of selective light transmission of a microcapsules dispersion, an encapsulated CLCs texture, and CLCs planar layer.

contain a cholesteric LC and selectively reflect the incident radiation, let us write down *Csca* in the form:

$$Csca = 2\pi/k^2 \sum_{n=1}^{\infty}\{(2n+1)(|a_n|^2+|b_n|^2)\} + Cref, \qquad (4)$$

where $k=2\pi n_b/\lambda$; n_b is the refractive index of the medium the capsules are suspended in; λ is the wavelength of the incident light. a_n, b_n are the scattering series coefficients for the enveloped capsules[6] :

$$a_n = \frac{\Psi n(y)[\Psi' n(m_2 y) - An\chi' n(m_2 y)] - m_2\Psi'(y)[\Psi n(m_2 y) - An\chi n(m_2 y)]}{\zeta n(y)[\Psi'(m_2 y) - An\chi' n(m_2 y)] - m_2\zeta' n(y)[\Psi n(m_2 y) - An\chi n(m_2 y)]}, \qquad (5)$$

$$b_n = \frac{m_2\Psi n(y)[\Psi' n(m_2 y) - Bn\chi'(m_2 y)] - \Psi' n(y)[\Psi n(m_2 y) - Bn\chi n(m_2 y)]}{m_2\zeta n(y)[\Psi' n(m_2 y) - Bn\chi' n(m_2 y)] - \zeta' n(y)[\Psi n(m_2 y) - Bn\chi n(m_2 y)]}, \qquad (6)$$

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$$An = \frac{m_2\Psi n(m_2x)\Psi' n(m_1x) - m_1\Psi' n(m_2x)\Psi n(m_1x)}{m_2\chi n(m_2x)\Psi' n(m_1x) - m_1\chi' n(m_2x)\Psi n(m_1x)} \qquad (7)$$

$$Bn = \frac{m_2\Psi n(m_1x)\Psi' n(m_2x) - m_1\Psi n(m_2x)\Psi'(m_1x)}{m_2\chi' n(m_2x)\Psi n(m_1x) - m_1\Psi' n(m_1x)\chi n(m_2x)}, \qquad (8)$$

where $m1$ is the relative (with respect to the surrounding medium) refractive index of the capsule core; $m2$ is the relative refractive index of the envelope; $x=ka$; $y=kR$; $\Psi n(z)$, $\chi n(z)$ - are the Riccati-Bessel functions; $\Psi' n(z) = \Psi n\text{-}1(z)\text{-}(n\Psi n(z)/x)$. $Cref$ is the extinction cross section of the selective reflection, which is determined in general case as

$$Cref = 2\pi R^2 \int_0^{\pi/2} r\cos\theta\sin\theta d\theta, \qquad (9)$$

where r is the selective reflection factor of the cholesteric, and θ is the angle of incidence. The expression for the selective reflection factor of the CLCs was approximated by the case of normal light incidence onto a planar layer of a cholesteric LC[7]:

$$r = (\delta^2 \sin^2 KL)/(16(K\eta^2/\tau)^2 + \delta^2 \sin^2 KL) \qquad (10)$$

where $K=\nu(1+\eta^2-(4\eta^2+\delta^2)^{1/2})^{1/2}$; $\nu=2\pi n_c/\lambda$; $\eta=\tau/2\nu$; $\tau=4\pi/p$; p is the helix pitch; n_c is the mean refractive index of the CLCs; λ is the wavelength of the incident light; L is the thicknesse of the CLC layer; δ is the anysotropy of the CLC.

The theoretical curves of light transmission for the microcapsules suspended in water were calculated numerically. In the calculations, the following physical parameters of the mediums under study were used: $n_o=1.51$; $n_e=1.49$; $n_b=1.33$; $p=0.35\mu m$, where n_o and n_e are the refractive indices of the ordinary and extraordinary CLCs beams, respectively. Figure 2 shows theoretical and experimental spectral dependences of the transmittance of polarized light for the mediums of interest. It is seen from the figure that almost throughout the whole wavelength range, the theory compares well with the experiment. Only in the spectral region of selective transmission, the measured width of the peak is appreciably broader than the predicted one. Figure 3 presents the calculated spectral dependences of light transmission by plane-parallel layers of CLCs microcapsules suspended in water for different layer thicknesses and helix pitchs (for Δn=0.02). The presence of the interference maxima is seen to be an inherent feature of all the calculated curves. It should be noted that the proposed model allows to perform modelling of properties and working characteristics of various thermosensitive mediums and may be useful for their purposeful selection by varying constituent components of such materials, their geometry and morphology.

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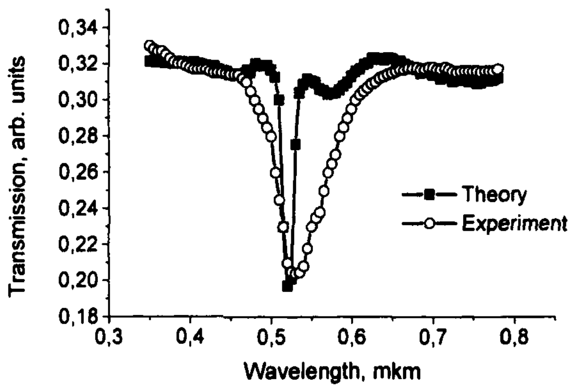

FIGURE 2 Theoretical and experimental spectral dependences of light transmission by a plane-parallel layer of microcapsules suspended in water. The layer thickness is 4 μm.

CONCLUSIONS

Aqueous dispersions of CLCs microcapsules selectively reflecting light have been studied both theoretically and experimentally. The preparation procedure used in

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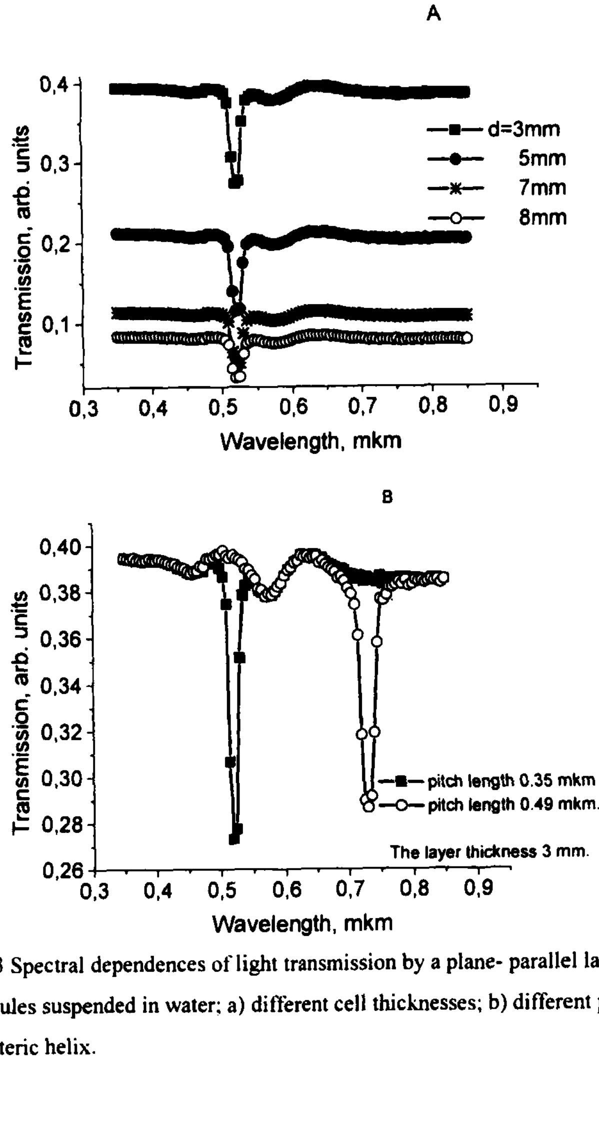

FIGURE 3 Spectral dependences of light transmission by a plane- parallel layer of microcapsules suspended in water; a) different cell thicknesses; b) different pitch of the cholesteric helix.

this work was shown to provide dispersions with the mean capsule size of 15 microns. The transmission spectra have been measured and spectral order parameters determined for the supermolecular textures of CLCs. The high value of the order parameter of the encapsulated CLCs (S=0.70) is indicative of rather a high degree of ordering of the LC molecules (for the planar CLC texture S=0.92). A theoretical model of light transmission of these materials is developed. Using this model, the effect of thickness of a plane-parallel layer of microcapsules suspended in water on the optical properties of the dispersion has been studied alongside with that of helix pitch and CLC anisotropy.

Acknowledgments

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