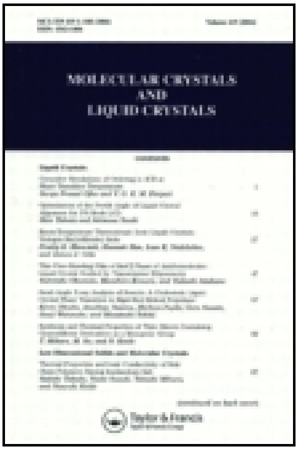

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Influence of Mechanical Deformation on Electrooptical Properties of Polymer Dispersed Liquid Crystal Films

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The influence of mechanical deformations such as stretching and bending on the electrooptical properties of the polymer dispersed smectic A (S_A) liquid crystal (PDLC) films has been investigated. The PDLC films were formed by the solvent induced phase separation method and cooling of the dispersed system to temperature below the temperature of N-phase to S_A-phase transition. The electrooptical behaviour based on field controlled light scattering and transmitting of the stressed and unstressed PDLC films was studied. The characteristic changes of the light transmittance and threshold voltage of electrooptical response in elastic deformed PDLC films are found. The physical nature of observed phenomena is discussed in connection with the change of PDLC morphology. The received data make it possible to evaluate the deformed PDLC film electrooptics and may be used for designing of the large-area sun-light-protection automobile composite glasses, switchable windows, orangery covers as well as flexible light valves and shutters.

Keywords: mechanical deformations; electrooptics; PDLC

INTRODUCTION

The polymer dispersed liquid crystal (PDLC) films form a new class of

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materials with many potential optical application due to their flexibility and the simple technologies of large-area film fabrication. These properties make them particularly useful for the video-devices exposing to a variety of deformations. It takes place when the film indicator should reproduce the form of examined object, e.g., contacting thermographic films for medicine and heat-technics, controlling surface apparatuses for the machine details or integrated plated circuits.

On the other hand, the random deformations of PDLC films arise as result of the influence of the uncontrollable vibrations, wind gusts etc. on the light-weaken films for automobiles and aeroplanes, the switchable windows and the sun-light-protection covers of hothouse or orangery.

Unfortunately, little is known at present about the effect of mechanical deformations on the electrooptical properties of PDLC films. The innumerable known-to-us papers involve researches of the light diffraction of cholesteric LC microdroplets deformed by PDLC technology [1] and the optical properties of stretched nematic PDLC films [2]. In this paper the influence of the stretching and bending deformations on electrooptcs of the polymer dispersed smectic A liquid crystal films has been investigated.

MATERIALS AND TECHNIQUE

The dispersed systems of smectic A LC-polymer consisted the polyvinylbutyrale polymeric matrix and LC multicomponent mixture on the basis of alkylbenzoic acid ethers and cyanobiphenyls [3]. The S_A-N and S_A-Cr transition occur at 62.0°C and 0°C respectively. The specific electroconductivity of LC mixture (σ) was varied by the concentration of ionic admixtures, such as tetrabutylammonium bromide and trimethylcetylammonium nonyloxybenzoate. The dielectric anisotropy ($\Delta\varepsilon = \varepsilon_{//} - \varepsilon_{\perp}$) and the anisotropy of eletroconductivity ($\Delta\sigma = \sigma_{\perp}/\sigma_{//}$) alter within the intervals of 8 – 12 and 1.7 – 2.2 respectively.

PDLC films were made by the solvent induced phase separation technology (SIPS-method) [4], taking into account the peculiarities of S_A phase state. LC was mixed with 14% polymer solution in ethylacetate and toluol. Prepared homogeneous mixture was poured out on the flat plate surface. During evaporation at the temperature lower than the solvent boiling temperature and higher than temperature of nematic LC – isotropic liquid phase transition, the appearance of two phases can be observed. After plate drying and cooling downto the S_A phase temperature, the polymer film with LC microdroplets of the rough ellipse shape was formed. The relative percentage by weight of LC was equal to 62.8.

The PDLC film thickness was altered from 18 μm to 24 μm. The LC microdroplets sizes were depended on evaporation speed and at our experimental conditions they were about 0.7-5.4 μm in diameter. The rectangle matrix of ITO transparent electrodes was formed on the film surface by the method of [5]. The electrooptical effects and structural transitions in PDLC films were traced by the general optical photometry and polarising microscopy methods.

The opaque state of PDLC film was formed by the low-frequency electric field ($f < 50$ Hz) exiting the electrohydrodynamic (EHD) flow in LC with $\Delta\sigma \neq 0$. The EHD circular flows degenerate to focal-conic (FC) steady domains after the perturbation field removal. The transparent state of PDLC film was formed by the high-frequency field ($F > 2.5$ kHz). Upon application of the field, the LC molecule in each droplet aligns in a direction parallel to the field at the cost $\Delta\varepsilon > 0$, and the film will switch to the transparent state. The transition driving was carried out by means of amplitude field increase from the threshold voltage (U_{th}) to saturation voltage (U_{sat}). The stability of any LC state after the field removal was provided by the structural and optical memory of smectic A LC [6].

The stretching of PDLC film was carried out by the mechanical device as illustrated in Figure 1. The sample was placed between two thin glass plates, each with a transparent matrix electrodes. The stretching and sample lengthening were set by micrometer screw. In addition, the film thickness was controlled by reflection of the laser light from the bounding plates. The stretch effort (F) was less than the elasticity limit of PDLC film and the stretching was stopped at the plastic deformation appearance.

The bend deformations were created by means of the film putting on surface of the glass hollow cylindrical segments with different radius (Figure 2a) and centrosymmetrical load (P) on the film fixed on the brackets (Figure 2b). The measuring of the electrooptical characteristics was carried out bend film length at the different flexure (h).

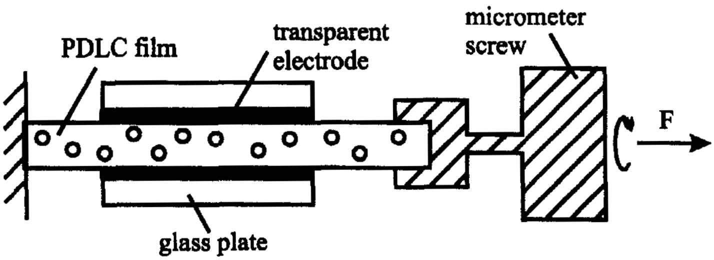

FIGURE 1. Configuration and operating principle of the stretch PDLC device. F is the stretch effort.

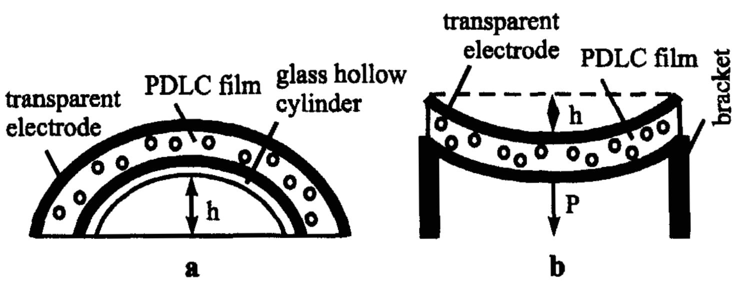

FIGURE 2. Illustration of two principles of PDLC film bending. h is the film flexure, P is the centrosymmetrical load.

RESULTS AND DISCUSSION

Threshold voltages of EHD instability and field orientation phase transition, light scattering and transmittance as a function of the PDLC film relative lengthening are given in Figure 3. The decrease of light scattering threshold voltage (U_{scat}) was connected with changing of the microdroplet surface curvature owing to PDLC film. The curvature changing stimulated the S_A layer breaking and the charge concentration in the broken places. It makes for EHD processes in LC microdroplets and received result supports the Carr-Helfrich theory [7].

In its turn, increase of the clearing threshold voltage (U_{cl}) means the rise of the energy barrier of the phase transition from focal conic to bipolar structure of LC microdroplets. According to Doane et al. [8], the rejection from the spherical droplet shape leads to increase of the clearing field threshold. In Vaz et al. experiments [8], the clearing threshold voltage of the nematic ellipsoidal droplets was twice as large as spherical droplet one.

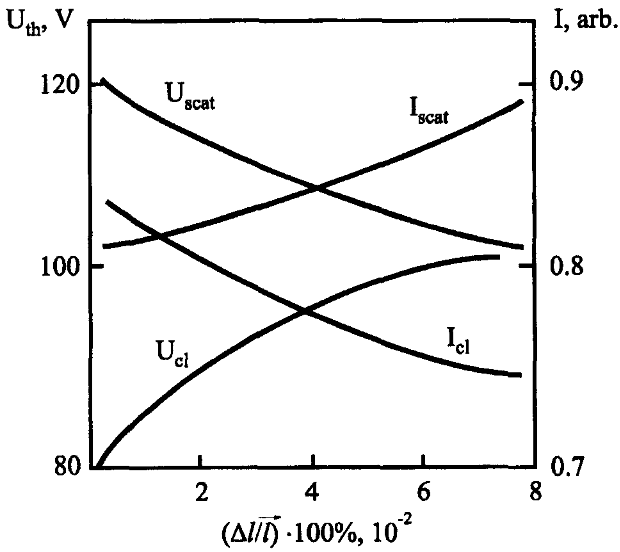

FIGURE 3. The threshold voltage of EHD instability (U_{scat}), threshold voltage of field LC reorientation (U_{cl}), light scattering (I_{scat}) and transmittance (I_{cl}) as a function of the relative PDLC film lengthening ($\Delta l/l$).

In our case, the theoretical dependence [7]:

$$U_{th}^{cl} \sim \frac{d}{a}\left(q^2 - 1\right)^{1/2} , \qquad (1)$$

where q is ratio of length of the major axis (a) to the minor one (b) of ellipsoid and d is the film thickness, was not observed.

We explain this disagreement as being due to the layer structure of S_A phase and presence of the ellipsoidal droplets with major axis aligned in a direction perpendicular to the PDLC film surface. The stretching of this droplets decrease q-ratio. Therefore, the threshold voltage increase was not greater than 80%.

In Figure 3 it will be seen that the light scattering increases a little at the film stretching. On our view, this increase is the result of the EHD flow alternation and decrease of the LC domain sizes observed in the polarising microscope field of vision. The number of LC domains increase simultaneously with decreasing their sizes. It means that the number of the light scattering centres in LC droplet volume increases too.

In its turn, the transmittance decreases with increase of PDLC film lengthening. The transmittance decrease was caused by the change of director distribution in LC microdroplets. The bipolar droplet structure and the direction of the molecular axes in the LC droplet centres along the electric field preserved. But the molecular director field was distorted near the droplet surface by alternation of the surface curvature and the boundary conditions.

The light scattering and transmitting in the stretched and bent PDLC films are much the same. But the sample optical-voltage characteristic becomes less steep as flexure increase and the contrast ratio maximum takes place at more highly saturated voltage (Figure 4).

We have an explanation of this dependence based on the next assumption. It is reasonable to suppose that there is the neutral or zero layer in the film cross section. The neutral layer goes through the film centre weight and preserve its sizes at the film bending (Figure 5a). The neutral layer separates the stretched and pressed film layers at bend deformation. The microdroplets being above zero-layer were stretched in the convex film and the microdroplets being below zero-layer were pressed (Figure 5b and Figure 3a). The opposite processes take place in the concave film (Figure 5c and Figure 3b).

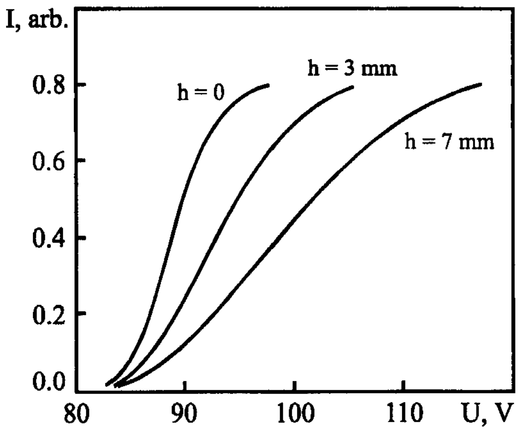

FIGURE 4. Transmittance-voltage characteristics of focal conic – bipolar transition for different flexure values.

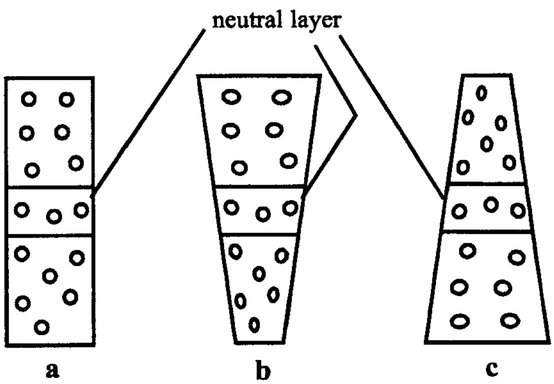

FIGURE 5. Cross-section of the undistorted (a), convex (b) and concave (c) PDLC films.

The molecular reorientation processes begin in the neutral and pressed film layers and spread to the stretched layers as the voltage grow. The number of the LC microdroplets having stretched ellipsoidal shape and ever growing field threshold of the molecular aligning increase proportional to distance to the neutral layer.

As a result, the slope of T-V curve is decreased as the flexure increase and q-ratio increase of the ellipsoidal droplets in the stretched PDLC film layers. On the basis of this mechanism, the scattering of convex and concave PDLC films can be expected to be the same as it was known experimentally.

Also, it follows from the experimental geometry that contrast ratio, measured along the length of flexed PDLC film, and contrast ratio of undistorted film, measured as a function of view angle, must be much the same. Indeed, the experimental curves differ slightly in appearance (Figure 6). However, the T-V curve of the deformed PDLC film is consistently lower than the undistorted one.

This behaviour was explained by two reasons. Firstly, it is an influence of stretched layers at the PDLC film bending. Secondary, it is the appearance of a nonuniform electric field by the bent electrodes of the deformed PDLC films.

Finally, it will be noted that the stability of scattering and transmitting properties of the deformed PDLC films are large because of the structural and optical memory of LC S_A phase. But the transmitted bipolar structure of LC droplets relaxes partly into focal conic domains in case of local strike-stress and optical uniformity of the PDLC film breaks as a whole.

CONCLUSION

The influence of the mechanical deformations on the electrooptical properties of the polymer dispersed smectic A liquid crystal films has been investigated. The alternation of scattering and transmitting of the stretched and bent PDLC films is connected, first of all, with changing of the dispersed system morphology. Received data may be used for estimation of electrooptics of the large-area PDLC flexible films exposing to external mechanical loads.

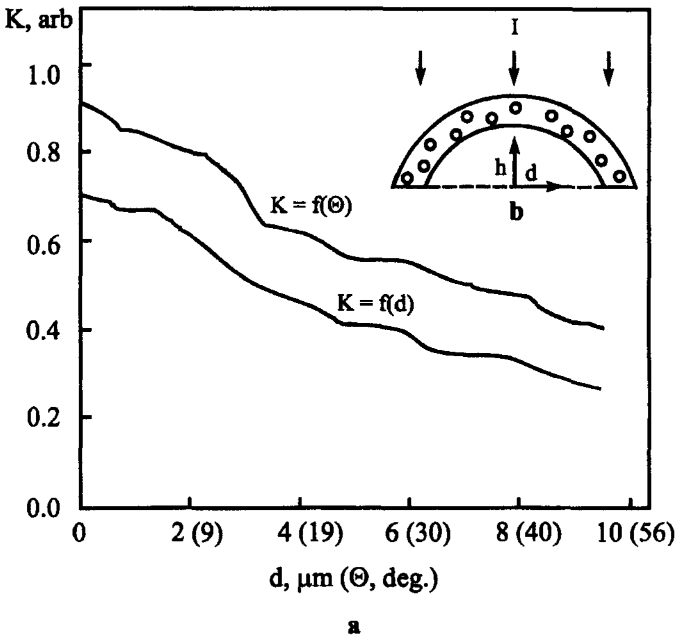

FIGURE 6. Contrast ratio ($K = I_{cl}/I_{scat}$) of undistorted PDLC film as a function of view angle (Θ) and K as a function of bent film length (a) at h = 12 mm (b).

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