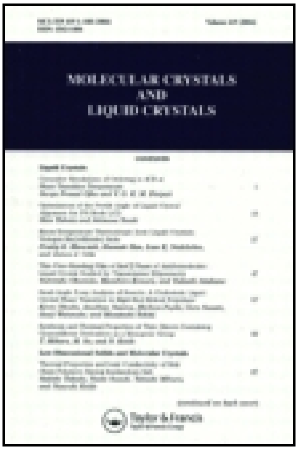

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Low Voltage Light Modulator Based on FLC Layer Divided by Polymer Walls

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The structural and electrooptical properties of low-voltage composite material are discussed. The material presents a planar-oriented layer of ferroelectric liquid crystal divided into smaller sections by polymer walls and may be used in light modulators with geometry of crossed polarizers.

Keywords: polymer dispersed liquid crystals; ferroelectrics; electrooptics

INTRODUCTION

Polymer dispersed liquid crystal (PDLC) [1] films are the prospect electrooptical material due to the utilizing of effect of electrically driving light scattering, simplicity of fabrication, reliability in work, flexible. However, there is one problem, which impedes progress in application of PDLC films in display devices. It is a high value of driving voltage. The high voltage causes by not only a large energy of surface interaction, but also a redistribution of electric field in dielectrically inhomogeneous medium.

As was discussed earlier [2], the electric field inside the LC droplets of composite films is not the same as the applied electric field E=U/D, where U is the applied voltage and D the total thickness of the PDLC layer. In the case of an isolated spherical droplet in a polymer matrix, the electric field inside LC droplet is expressed by:

$$E_{lc} = \frac{U}{D} \cdot \frac{3}{(\varepsilon_{lc} \; \varepsilon_p + 2)} \tag{1}$$

where ε_{lc} and ε_p are the dielectric constants of the liquid crystal and polymer, respectively. Usually, $\varepsilon_{lc} > \varepsilon_p$, for example, a parallel component of dielectric constant of LC 5CB [3] at low frequency is equal 18, ε_p of polyvinylbutyral is equal 6. Consequently, electric field inside 5CB droplets will be $E_{lc} = 0.6 \cdot U/D$. There is only one way to increase value of E_{lc} up to U/D, namely to choose composition so, that $\varepsilon_{lc} = \varepsilon_p$. The problem is more actual for the polymer dispersed ferroelectric liquid crystals (PDFLC), since a value of proper FLC dielectric constant in this case may be reached 100 and more.

The present paper deals with low-voltage composite films based on planar-oriented layer of ferroelectric liquid crystal divided into smaller sections by polymer walls. In the first part, we analyze the specific features of a field distribution inside composite films with strongly oblate LC droplets and discuss how to decrease driving voltage. In the second part we describe structure and electrooptical characteristics of above mentioned PDFLC material.

FIELD DISTRIBUTION INSIDE PDLC FILMS WITH STRONGLY OBLATE DROPLETS

A morphology of planar oriented PDFLC films [4-7] differs substantially from the structure of PDLC prepared by traditional way [2]. A strong deviation of droplets shape from a sphere is characteristic of the PDFLC films. In practice, the droplet cavities become very flattened during the fabrication of the planar oriented structure. The large droplets (with size strongly exceeded a thickness of PDFLC film) have soon disk-like form than ellipsoidal one (see Figure 1). In-plane size of such droplets is much more than the lateral one.

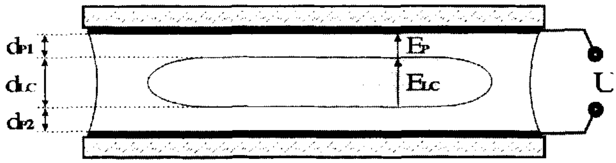

FIGURE 1 Schematic drawing of cross-section of the planar oriented PDLC film with strongly oblate droplets.

The distribution of electric field inside these PDFLC films can be approximately described as in lamellar structure. Proceedings from requirements of continuity of εE vector in dielectric multilayer structure yields the electric field E_{lc} in LC droplet as:

$$E_{lc} = \frac{U}{D} \cdot \frac{1 + \frac{d_p}{d_{lc}}}{1 + \frac{\varepsilon_{lc}}{\varepsilon_p} \cdot \frac{d_p}{d_{lc}}}, \tag{2}$$

where d_{lc} is the thickness of LC droplets, $d_p = d_{p1} + d_{p2}$, $D = d_p + d_{lc}$. Likely to the case (1), E_{lc} is equal to applied electric field U/D, if to choose components with $\varepsilon_{lc} = \varepsilon_p$. But, as it results from (2), there is another way to increase E_{lc} up to U/D. It occurs at any ratio $\varepsilon_{lc} / \varepsilon_p$, if we reduce the total thickness d_p of polymer layers relatively to the lateral size d_{lc} of LC droplet. Then $d_p / d_{lc} \Rightarrow 0$, and $E_{lc} \Rightarrow$ U/D.

For example, in the case of spherical droplet of FLC with $\varepsilon_{lc} = 100$ dispersed in polyvinylbutyral matrix, $E_{lc} = 0.16 \cdot U/D$ (see Eq.(1)). For the strong oblate droplets $E_{lc} = 0.11 \cdot U/D$ (see Eq.(2)), if $d_p = d_{lc}$. But the value of electric field E_{lc} increases up to $0.86 \cdot U/D$, if $d_p = 0.01 d_{lc}$.

We applied the second way in our experiments to prepare low-voltage PDFLC material.

EXPERIMENTAL

We used epoxy compound as a polymer matrix, in which ZhKS-302A ferroelectric liquid crystal mixture (P.N.Lebedev Physical Institute) was dispersed by polymerization induced phase separation (PIPS method) [1,2]. The FLC mixture is chiral smectic C* at room temperature and characterized by the following parameters: spontaneous polarization $P_s = 60$ nC/cm^2, tilt angle $\theta = 22°$, $T_{CA} = 53°C$, spiral is practically unwound. FLC is mixed thoroughly with epoxy resin and curing agent in the ratio of 4:5:1 by weight. The material is placed between two substrates with transparent electrodes. The uniaxial structure of PDFLC film is formed by shearing deformation during the curing process. Film thickness was approximately 4μm.

Figures 2a,b show the typical structure of prepared samples in geometry of crossed polarizers. In the main, the liquid crystal fills large pores having strongly elongated form. The sizes of pores are 80÷300μm in length and 8÷20μm in width. Texture studies by using polarizing microscope show that the smectic layers in the whole of the pores are orthogonal to the substrates. The normal to smectic layers is mainly oriented perpendicularly to the direction of the shear deformation.

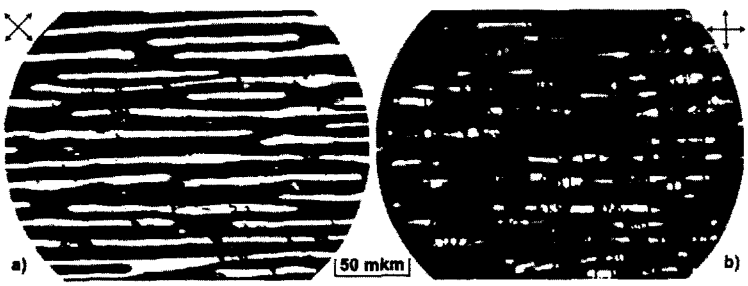

FIGURE 2 Optical microscope picture of PDFLC sample under study in crossed polarizers. Polarizer and composite film orientation are parallel (b) and at an angle 45° (a).

Corresponding refractive indexes of used components aren't mismatched resulting in a small anisotropy of transmittance of polarized light. Figure 3a,b illustrates that there is no transparent condition at any orientation of light polarization relatively to direction of film deformation. Therefore the scattering mode [4,6] cannot be applied for the light modulation in this case. But the cell reveals a relatively high contrast if it is placed between two crossed polarizers, that make this geometry attractive to design light modulators.

The most of the droplets are isolated, but some of them are connected with each other. By another words, such structure may be presented as a planar oriented FLC layer divided into smaller sections by polymer walls. From observation of cross-section of PDFLC film we found that the polymer layers separated the pore from the substrates are either very thin (<<1 μm) or quite absent. It means (see Eq.(2)), that in this case the driving voltage must be low.

Dynamic of electrooptic response and volt-contrast curve of the PDFLC cell are shown in Figures 4 and 5, respectively. Really, as can see in Figure 5, it is sufficient applied voltage U=6V to reach contrast ratio 30:1. Such value of driving voltage is comparable with one for the light modulators based on pure FLC layers.

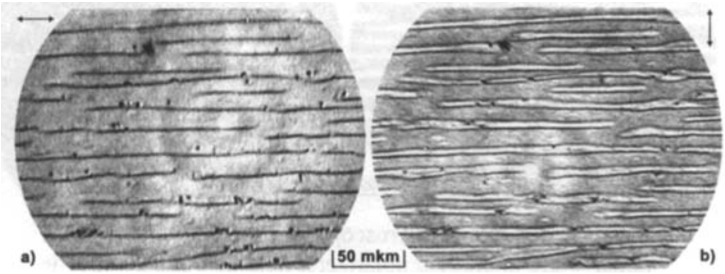

FIGURE 3 Microphotos of the same part of the film, as in Figure 2, in the geometry of just one polarizer. Light polarization coincides with the film orientation (a) and is perpendicular to it (b).

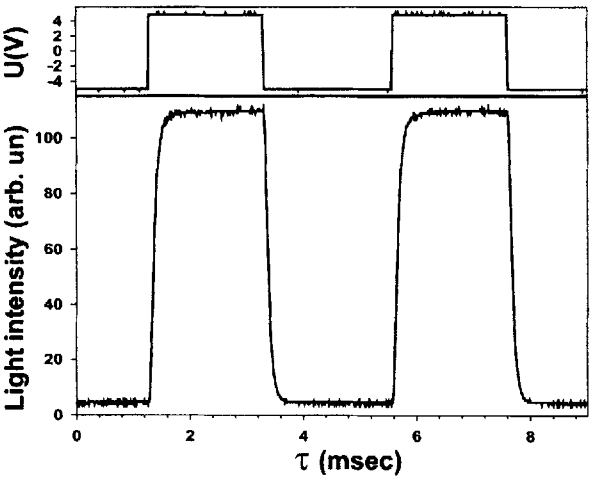

FIGURE 4 Typical oscillograms of electrooptical response of the composite film.

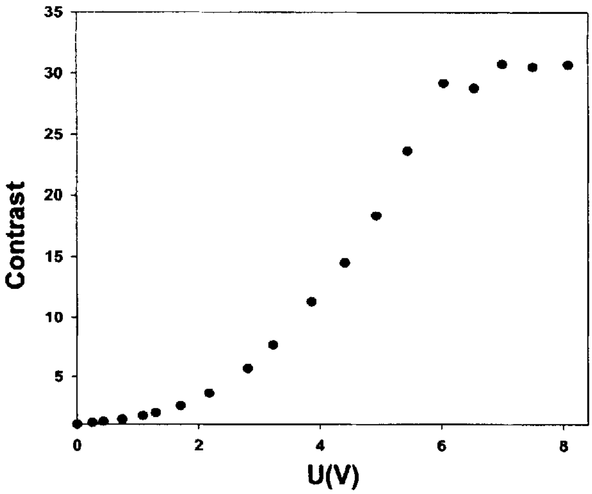

FIGURE 5 Volt-contrast curve of PDFLC cell with crossed polarizers.

CONCLUSIONS

We have analyzed two different ways to decrease driving voltage in planar oriented PDLC films with strongly flattened droplets. One of the methods is realized in composite material developed in this work. Approximately, the material can be described as a planar oriented FLC layer divided into smaller sections by polymer walls. Low driving voltage (less than 6V) is characteristic of such films.

Negative feature of the material is a small brightness. Maximum transmittance of the cell with crossed polarizers is less than 20% (usually <10%), while the one of Clark-Lagerwall cell [8] can reach 45%.

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