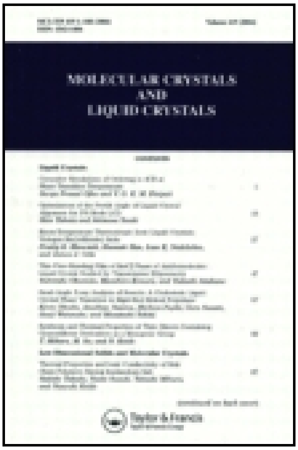

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Uniaxially Oriented Films of Polymer Dispersed Liquid Crystals: Textures, Optical Properties and Applications

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Overview of authors works on uniaxially oriented films (UOF) of polymer dispersed liquid crystals (PDLC) including nematics, cholesterics and ferroelectric smectics are presented. The interference effects such as the oscillations of volt-contrast curves and the quenching of a light transmitted through the nematic PDLC are described. Exceptional behaviour of polarization efficiency revealed in sheared cholesteric PDLC films alive is discussed. We have found the electro-thermooptical hysteresis in cholesteric PDLC and proposed laser-addressed reverse information recording based on it. Structure, optical, dynamic and temperature properties of UOF PDLC based on ferroelectric smectics are presented. Using this material, a single-polarizer and three different types of polarizer-free light modulators were designed.

Keywords: cholesterics; nematics; polymer dispersed liquid crystals; smectics

INTRODUCTION

For the first time the uniaxially oriented films of polymer dispersed liquid crystals have been prepared and studied by Sonin et al. [1]. They have found an anisotropy of selective light scattering and transmission spectrum of uniaxially stretched films of polymer dispersed cholesterics liquid crystals (PDChLC). J.L. West et al. [2] have

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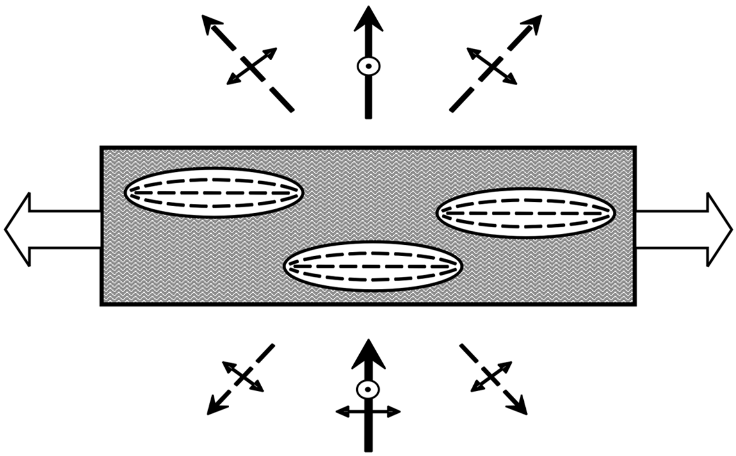

FIGURE 1 Scheme presented a polarization of the light passed through the stretched PDLC film with uniaxially arranged ensemble of elongated bipolar nematic droplets.

patented a similar effect in uniaxially stretched or sheared films of polymer dispersed nematic liquid crystals (PDNLC) for manufacturing a scattering polarizer. In that case the bipolar nematic droplets inside the film have ellipsoidal form with the long axes oriented along a direction of deformation (Fig. 1). As follows from [3,4], the bipolar axes of director configuration within such droplets coincide with their long axes. If a refractive index of polymer n_p is matched to perpendicular component of refractive index $n_{\perp lc}$ of LC, the light polarized perpendicularly to the tensile passes through a film and light polarized along the stretching is intensively scattered. A shear deformation of composite film generally orients the ensemble of bipolar nematic droplets not in a plane of a film, but at some tilt angle, for example, near 30° [5].

Besides there are other ways to create uniaxially arranged ensemble of LC droplets, for example, by applying electric or magnetic field in a plane of composite film during the polymerization of a matrix [6]. The unidirectional orientation of LC droplets remains after switching off a field, but in this case not due to deformation of droplets, and to orienting influence of polymer walls which macromolecules were aligned alone a field. Another method of preparing of UOF PDLC is based on the use of anisotropically photocured polymer matrix [7] in which an uniaxial order of macromolecules occurs under exposure to a linearly polarized light.

The paper presents brief review of the studies of UOF PDLC [8–30] carried out by authors in L.V. Kirensky Institute of Physics of Siberian Branch of Russian Academy of Sciencies.

UNIAXIALLY ORIENTED PDNLC FILMS

We carried out special works on the optimization of manufacturing techniques and investigated the optomechanical properties of UOF PDNLC [7–15]. Figure 2 shows the perpendicular $T_\perp$ and parallel $T_\|$ component of light transmission and their contrast ratio $T_\perp/T_\|$ depending on a strain $\Delta L/L_0$ for the stretched PDNLC film. The value of $T_\perp/T_\| \approx 410$ at $\Delta L/L_0 = 0.5$, that corresponds to an efficiency of high-quality conventional polarizers based on light absorption anisotropy. This value is not a limit, it may be increased, for example, by thickening the films, but the transmittance of perpendicular component will decrease in that case. Reduction of the $T_\perp/T_\|$ ratio at $\Delta L/L_0 > 0.5$ is caused entirely by thinning of composite film, since the anisotropy of light scattering coefficient $(k_\| - k_\perp)$ grows smoothly in this interval of strain values [8].

The operational temperature range of the scattering PDLC polarizers correlates with an interval of LC mesophase. As against the prism

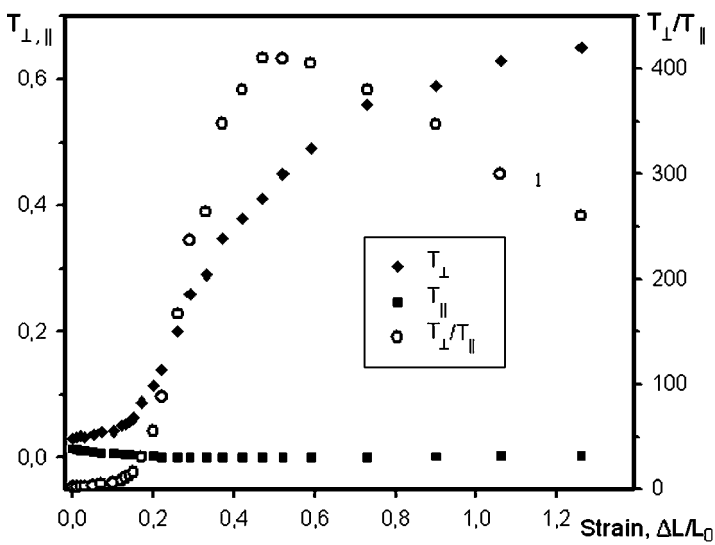

FIGURE 2 Transmittances and their ratio for He-Ne laser beam (0,633 nm) polarized perpendicular and parallel to the stretch axis of PDNLC film [8]. L_0 is the initial film length, ΔL is its elongation.

polarizers, UOF PDLC films are compact and simple in manufacturing, as well as absorbing polarizers. But in comparison with the last, they have conclusive advantages. Firstly, PDLC films can be used for polarization of powerful radiation, because “unnecessary” light component scatters by this material, and it is heating less, than absorbing polarizers in which such component of light is absorbed causing their destruction. Secondly, PDLC films effectively polarize light in all visible and near infrared range, while absorbing polarizers only inside absorption band of dichroic dyes.

Nevertheless the most interesting feature of scattering PDLC polarizers is the opportunity to operate polarizing efficiency by electric field. The typical kind of transmittance curves and $T_{\perp}/T_{\parallel}$ ratio of scattering polarizers depending on applied voltage are shown in Figure 3.

To investigate a correlation between composite morphology and optical properties, we prepared the monolayer PDLC films in which the droplets were arranged in a single layer without overlap each other. Studying such samples, we have found that volt-transmittance curves reveal the oscillation behavior (see Fig. 4) [9–15]. At that, such oscillations are observed distinctly only for monolayer PDLC films with large droplets. A number of the oscillations and their amplitudes depend on many factors: droplet size, birefringence $\Delta n = n_{\parallel} - n_{\perp}$, wavelength, etc. This effect has an interference origin and appears

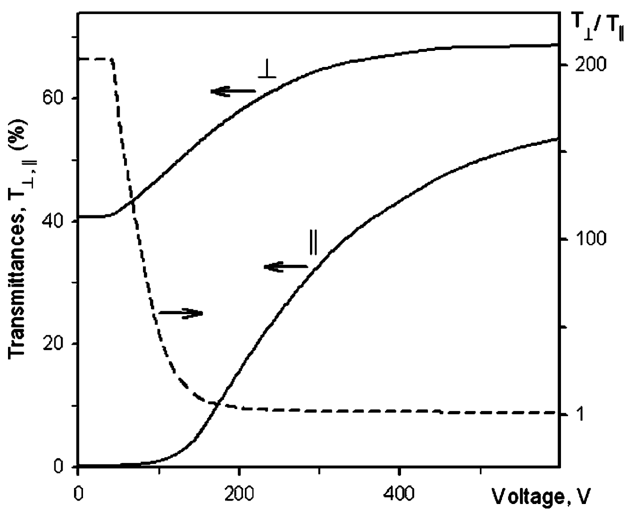

FIGURE 3 Transmittance components $T_{\perp}, T_{\parallel}$ and their ratio $T_{\perp}/T_{\parallel}$ for thick sample of UOF PDNLC depending on applied voltage.

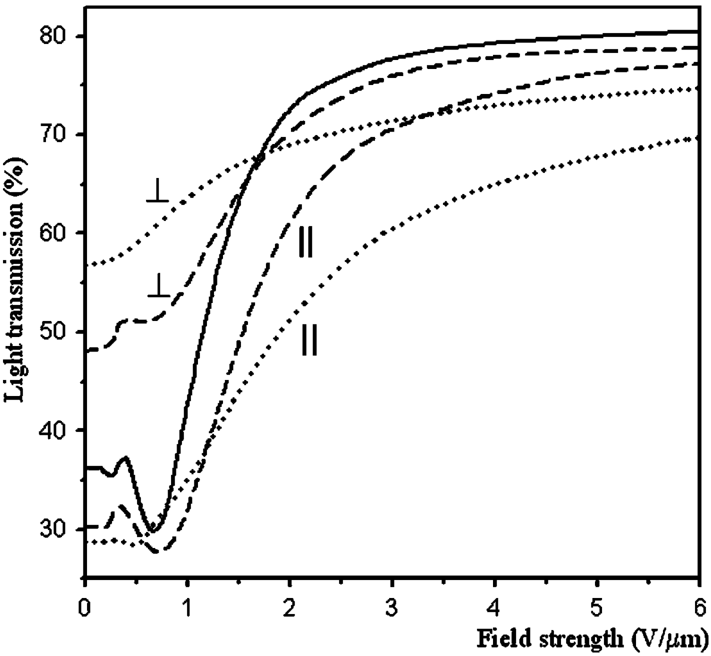

FIGURE 4 The oscillations of transmittance curves of monolayer PDNLC film in initial state (solid line), for the strain 37% (dashed line) and for the strain 167% (dotted line). It is shown the parallel (||) and perpendicular (⊥) components.

due to superposition of two light beams passed through the LC droplets and between them. Applied voltage causes a variation of phase retardation between these beams which results in the oscillations.

One of the consequences of the interference effect is an opportunity to quench directly transmitted light if two above-mentioned beams will be in opposition and have equal intensity. In collaboration with a team headed Prof. V. Loiko, we simulated a required morphology of PDLC films and demonstrated (see Fig. 5) the effect of interference quenching [13]. This effect gives a chance to create high-contrast PDLC light modulators with low-voltage operation [14]. The effect reveals not only in static mode of operation, but in dynamical mode as well [15] that is very important for a display applications.

We have found [9–12] that for some kinds of PDNLC compositions, for example, in the case of a mixture of polyvinylbutyral and nematic 5CB, director configuration inside all bipolar LC droplets is characterized by rigidly fixed poles, which positions are independent of applied

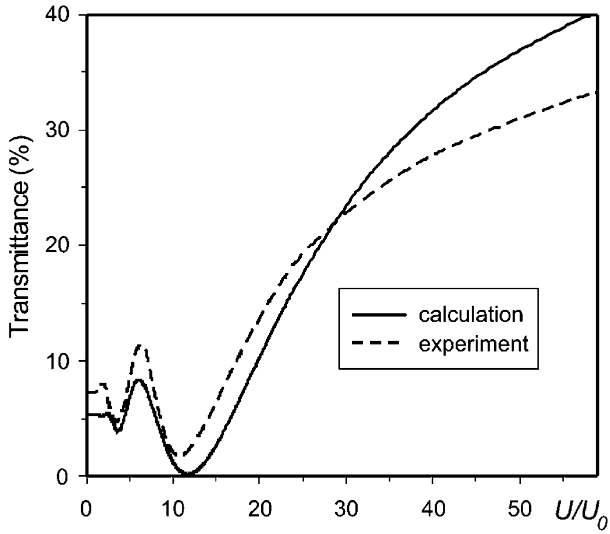

FIGURE 5 Interference quenching effect in UOF PDNLC film for the light polarized parallel to the stretch direction. U_0 is a threshold field.

voltage. We have developed theoretical method to simulate 3-D model of the orientational structure within such elongated bipolar droplets [10,11], which permit us to predict a dual process of its reorientation: a threshold process in the region where the initial director orientation is orthogonal to the electric field, and a nonthreshold one in the remainder of the droplet volume. Experimental investigations of the properties of scattered light for PDNLC film [10–12] have confirmed our computational results.

UNIAXIALLY ORIENTED PDChLC Films

More complicated effects are observed in UOF of polymer dispersed cholesterics (chiral nematic) liquid crystals (PDChLC) [16–19]. Director configuration, its transformation in electric field, optical response of such films dependent strong on the content C_{ch} of chiral admixture in nematic. For small C_{ch} value the droplets structure and volt-contrast curves of the films is similar mainly to the ones without dopant. Dramatic change of these parameters reveals for the middle C_{ch} values [16–18]. Figure 6 shows the transmittance curves of light polarized components and their ratio for UOF PDChLC based on polyvinylbutyral and a mixture of cyanobiphenyls with 5% of cholesterylacetate as a chiral dopant. As can see, this film can be at various voltages in

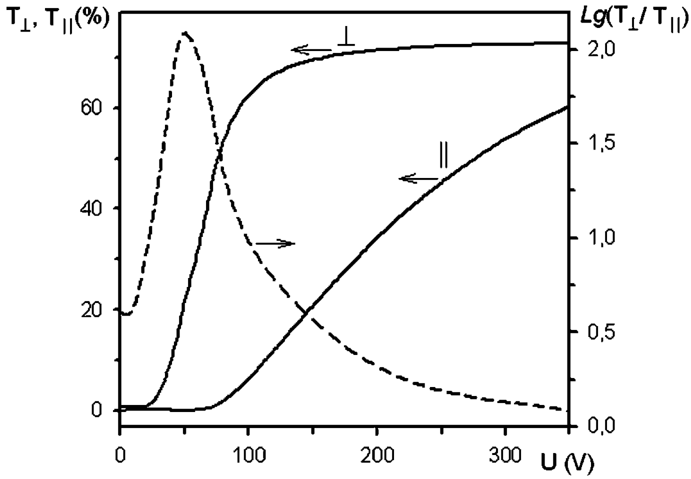

FIGURE 6 Transmittance components $T_{\perp}, T_{\|}$ and a logarithm of their ratio $T_{\perp}/T_{\|}$ for UOF PDChLC depending on applied voltage.

three different optical states: to scatter the light of any polarization, to scatter only one linearly polarized component, to be transparent for the whole of light beam. Thus we have developed the electrooptical material for polarization-selective modulation of light. For the high C_{ch} value the volt-contrast curves of UOF PDChLC have additionally the range characterized by inversion of a ratio of transmittance component [19].

Strainless PDChLC films reveal large hysteresis of the volt-transmittance curve that allows in principle to use them in flat panel displays with the passive-matrix addressing. Besides we have found the effect of electro-thermooptical bistability in such films and considered the opportunity of its use for thermooptical reversive recording of the information [20,21]. On basis of these data the method of laser-addressed recording in bistable PDChLC films doped by special dye in normal and inverse scattering mode have been developed [21].

UNIAXIALLY ORIENTED PDFLC FILMS

High-frequency electrooptical material representing an uniaxially oriented films of polymer dispersed ferroelectric liquid crystals (PDFLC) has been developed in 1991 [22,23]. Characteristics of PDFLC films depending on material constants of FLC and polymer, smectic structure inside droplets, morphology of the film and parameters of control field have been studied [24–30]. The manufacturing

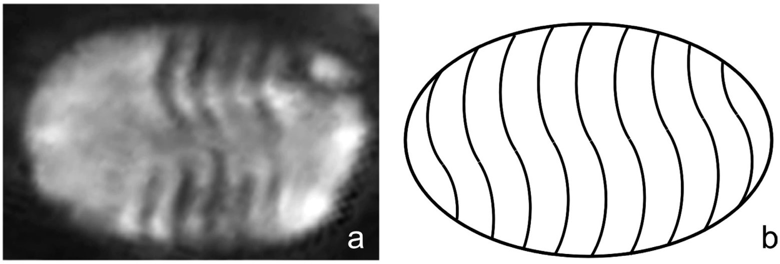

FIGURE 7 (a) FLC droplet with wavy type disclinations in crossed polarizers and (b) schematic presentation of corresponding structure of smectic layers within the droplets.

technique of the films have been optimized to obtain maximum anisotropy of its transmittance. The data on preparing methods, composition of UOF PDFLC films, and their structural, optical and electric properties is submitted in [24–30]. The high optical anisotropy of UOF PDFLC film is achieved only in the samples with the droplets possessing a wavy type structure (Fig. 7).

There are two basic ways to modulate the light intensity by using PDFLC films. Firstly, PDFLC films can be used as a phase plate placed in traditional layout between two polarizers. The second method is based on light scattering effect [22–30]. The light scattering PDFLC modulators in its turn may be both with a single-polarizer [22–26,29,30] and polarizer-free [27].

A design of one of polarizer-free modulators is shown in Figure 8. It consists of two PDFLC cells arranged in series. Composite films in the upper and lower cells are identical but electric field for them is applied in opposite directions. The components of PDFLC material are chosen so that the refractive index of polymer matches to the perpendicular components of refractive index of liquid crystal. In Figure 8a the directors in both PDFLC films under the applied field are oriented parallel (along X-axis). In this case, light with polarization along the Y-axis passes through the device without scattering. This situation is equivalent to the system of two parallel polarizers.

If the polarity of electric field changes (see Fig. 8b), the directors will turn at an angle 2θ (where $\theta = 22.5^\circ$ is a tilt angle of smectics molecules) while still remaining in the film XY-plane. Directors in the upper and lower films will turn in opposite directions from the X-axis so that resulting angle between them becomes $4\theta = 90^\circ$. In this state, the PDFLC valve will scatter light of any polarization because such arrangement is similar to a system of crossed polarizers.

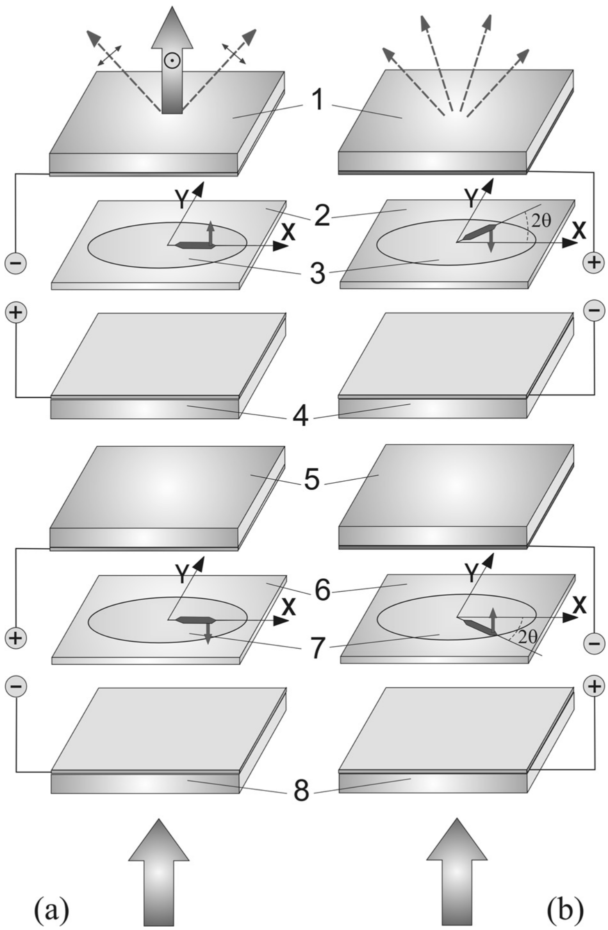

FIGURE 8 The design and operation principle of polarizer-free light modulator based on double PDFLC cell. 1,4,5 and 8 are the substrates with transparent electrodes; 2 and 6 are the polymer matrixes; 3 and 7 are FLC droplets.

Moreover we have proposed another two modifications of PDFLC light modulators without polarizers [27]: based on bilayer PDFLC film and on the composition of FLC with LC-polymer matrix. Additional advantage of the polarizer-free PDFLC devices is an opportunity to use commercially available FLC mixtures with an angle $\theta = 22.5^\circ$, (in contrast to the exotic FLC with $\theta = 45^\circ$ required for a single-polarizer modulators) as such value of tilt angle is optimum for these designs. We have developed a theoretical model [29,30] for the simulation of optimal combination of material parameters and PDFLC modulator design required to reach its proper operational characteristics.

Pilot samples of light modulating PDFLC cells with the following performance parameters have been made: contrast ratio up to 60:1, saturation voltage $25 \div 30\,\text{V}$, reswitching time $30\,\mu\text{s}$ in smectics C^* phase and less than $1\,\mu\text{s}$ in smectics A^* phase, maximal transmittance up to 35%, limiting density of radiation power $4\,\text{kW/cm}^2$.

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