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Aligning Effect of Magnetic Field on PDLC Films During the Phase Separation

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ABSTRACT

The results of the study of the uniaxially oriented PDLC films prepared by solvent induced phase separation (SIPS) method are presented. The samples were obtained applying a longitudinal magnetic field while the phase separation of the liquid crystal and polymer occurs due to the evaporation of common solvent from the uniform solution. In the presence of magnetic field the nematic liquid crystals 4-n-pentyl-4'-cyanophenylcyclohexane (5PCH), the 4-n-pentyl-4'-cyanobiphenyl (5CB) and nematic mixture LN-394 form the separate droplets in polyvinylbutyral (PVB) matrix. At that, the nematics 5PCH and LN-394 form always the stable bipolar structures with the order parameter of the droplet axes depending on the value of the applied field. In 5CB droplets the bipolar structure is realized only in a weak magnetic field and the radial one is formed in a strong magnetic field. At intermediate field the non-equilibrium structures are appeared that are characterized by the flickering textures.

Keywords: nematic liquid crystal, director configuration, surface anchoring, magnetic field

1. INTRODUCTION

The uniaxially oriented films of polymer dispersed liquid crystals (PDLC) are the perspective material for the display application [1-4]. One of the methods to form the uniaxial orientation of the droplet ensemble in PDLC is the stretching of composite film in the certain direction [1, 3, 4]. After deformation the droplet form becomes ellipsoidal with the long axes oriented along the direction of the tension. The uniaxial alignment of the droplet ensemble depends on two mechanisms: the droplet anisometry and the anisotropy of surface interaction of LC molecules with the polymer wall. In the ellipsoidal droplets with the tangential boundary conditions the minimum of elastic energy of nematic liquid crystals (NLC) corresponds to the bipolar director configuration with the orientation of the symmetry axis along the maximal droplet axis. Moreover, the macromolecules in the elongated polymer matrix are oriented predominantly along the direction of tension that, in turn, stimulates the orientation of NLC molecules in the same direction. Thus, the both mechanisms lead to the same result enhancing each other. However it is difficult to fabricate the uniform PDNLC film because this method may result in the structural imperfections and local breaks of polymer matrix [3, 4].

In this respect another method based on the application of electric or magnetic field during the phase separation is more advantageous since it allows to form the homogeneous composite film free from structural defects. Earlier [1, 2] it has been shown that the influence of the transverse electric or magnetic field applied in process of LC droplets formation inside photocured matrix results in the creation of the films with progressively lower off-state scattering and threshold voltage. So far the application of the field along the composite film plane is not examined yet. However this procedure can be more interesting since it opens the alternative way to fabricate the uniaxially oriented PDNLC films. In the paper we present the results of the study of PDNLC films with uniaxially oriented droplet ensemble prepared by SIPS method.

2. SAMPLE PREPARATION

The following liquid crystals were used for the sample preparation:

1. The nematic 4-n-pentyl-4'-cyanophenylcyclohexane (5PCH) with the refractive indices $n_{\parallel} = 1.582$; $n_{\perp} = 1.496$ at

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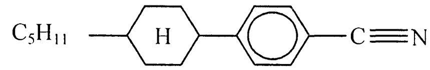
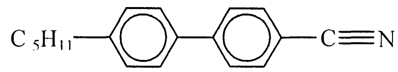
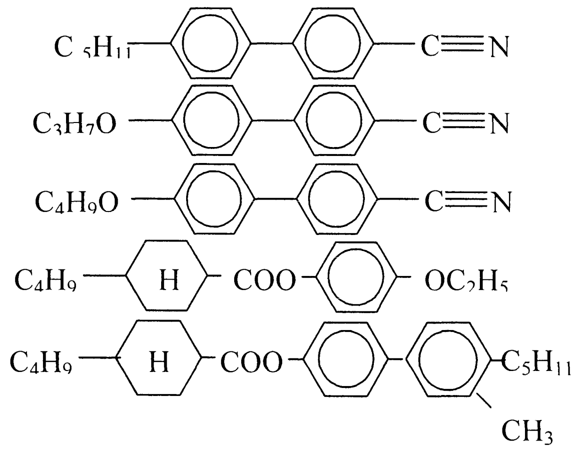
T = 44°C [5], transition temperatures Cr - 30°C - N - 54°C – Is and molecular structure



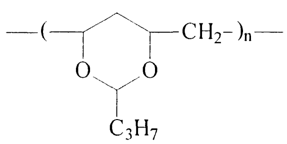
2. The nematic 4-n-pentyl-4'-cyanobiphenyl (5CB) with $n_{\parallel} = 1.725$; $n_{\perp} = 1.534$ [7], at T = 22°C, transition temperatures Cr – 22°C – 35°C – Is and molecular structure



3. The nematic mixture LN-396 with $n_{\parallel} = 1.69$; $n_{\perp} = 1.52$ at T = 24°C, transition temperatures Cr - 20°C -N - 64°C - Is. and molecular structures



Thermoplastic polyvinylbutyral (PVB) with $n_p = 1.488$, the glass transition temperature $T_g = 57$°C and molecular structure



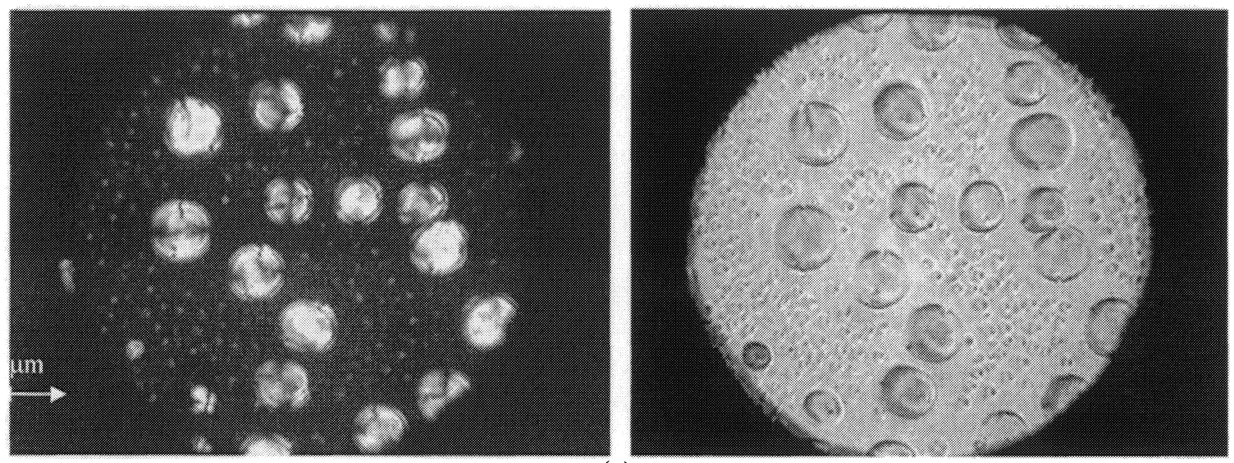
was used as the polymer matrix. As is known [7], PVB can be used as the surfactant forming the tangential boundary conditions for the nematics based on alkylcyanobiphenyls. It means that for NLC being investigated should be expected the formation of the droplets with the bipolar director configuration.

The NLC and polymer in the 2:3 ratio by weight were dissolved in ethyl alcohol. The obtained homogeneous solution was poured out on the glass substrate. The ratio of the solvent content to the summary weight of NLC and polymer was varied in the range of 5:1 ÷ 10:1. To orient the film during phase separation the samples were placed either between the poles of the electromagnet generating the field up to 25 kOe or inside the cylindrical channel of solenoid with the field up to 150 kOe. Magnetic field was applied along the film plane. During the alcohol evaporation (15 ÷ 30 minutes) the mixture became heterophase forming the PDNLC film.

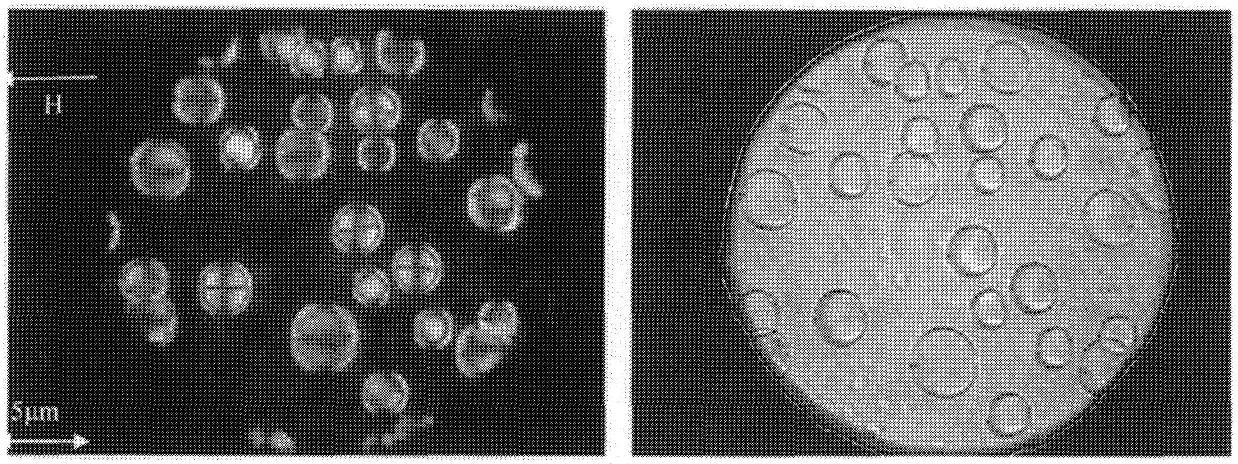
The samples with the monolayer arrangement of NLC droplets were prepared. The droplet size determined by the rate of solvent evaporation was varied in the limits 1 ÷ 12 μm. The textural patterns of the composite films were examined by the polarizing microscope.

3. RESULTS AND DISCUSSION

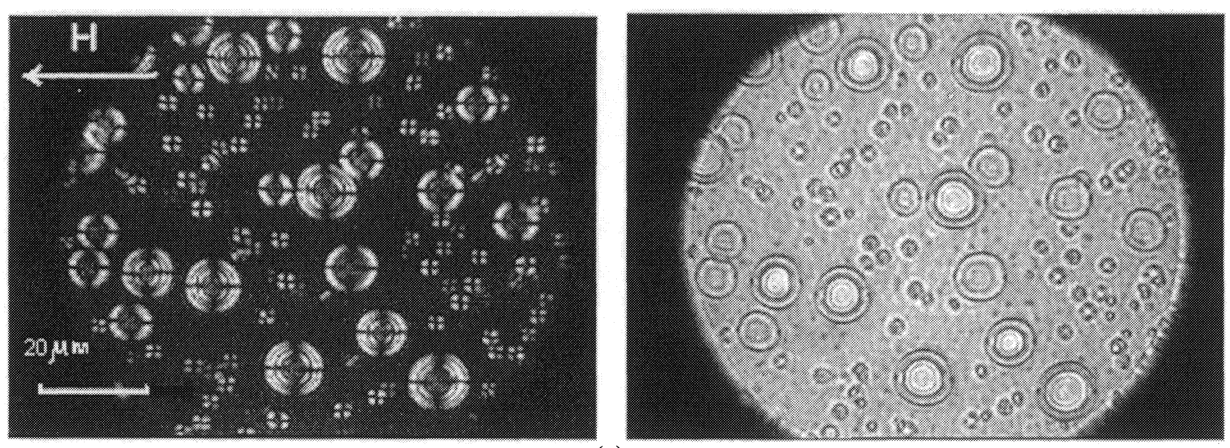
The texture analysis has revealed the bipolar director configurations formed inside the droplets of 5PCH and LN-396. The orientation order within the droplet ensemble depends on the value of the magnetic field applied during the phase separation. The bipolar axes of the droplets are aligned randomly in the sample prepared without the field (Fig. 1a). The orienting effect of magnetic field is sufficiently noticeable already for the intensity H = 22 kOe (Fig. 1b). At the stronger field H = 87 kOe (Fig. 1c) the bipolar axes are perfectly aligned along the magnetic field in the whole of the droplet ensemble.



(a)



(b)



(c)

Fig. 1. Microphotos of the PDNLC films observed in the polarizing microscope. The polarizers are crossed (left) and parallel (right). (**a**) The sample based on 5PCH formed at the magnetic field H = 0; (**b**) the same composition obtained at H = 22 kOe; (**c**) the sample based on LN-396 prepared at H = 87 kOe.

To estimate the arrangement of PDNLC films we calculated the order parameter Q of the bipolar axes. In this case, the Q value is determined by the same way as the order parameter of NLC molecules but taking into account that the disorder of bipolar axes occurs only in the film plane.

The dependence of the order parameter Q on the field H for the 5PCH droplets of 1 ÷ 5 micron size is shown in Fig. 2. Evidently the ordering of the bipolar axes begins from the field H_c = 4.3 kOe. The strong increase of the orienting effect on the droplet's order is revealed above H_c. The parameter Q grows in the range of the field H = 4.3 ÷ 28.5 kOe from 0 to 0.8. Then the Q (H) dependence approaches to the saturation. At the value of H = 87 kOe the perfect orientation of the droplets axes along the H direction occurs. The uniaxially oriented PDNLC films obtained by this method remain stable for several years. The analogous Q(H) dependence is manifested for composite films with LN-396.

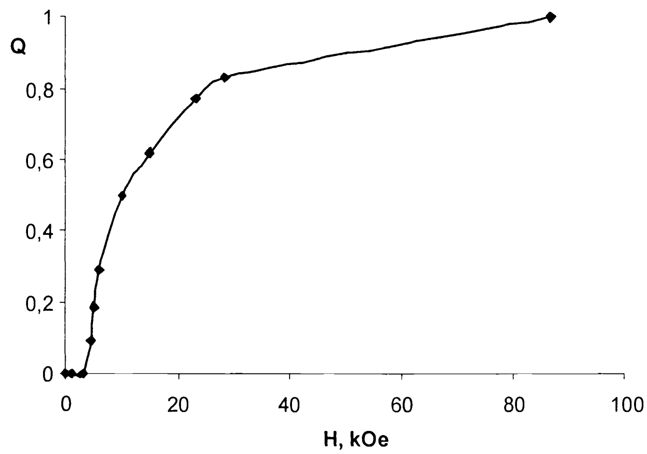


Fig. 2. The order parameter Q of the bipolar axes for 5PCH droplets versus the magnetic field strength H applied during the formation of PDNLC film.

Analysis of the 5CB droplets texture has been shown that the bipolar director configurations are formed only at weak magnetic field H ≤ 4 kOe (see Fig. 3). The radial structures with point defect - hedgehog in the droplet center begin to form when the field exceeds 4 kOe. Consequently, in this case the surface anchoring for 5CB molecules is homeotropic. When the magnetic field rises from 4 to 7 kOe the percentage of radial structures increases from 0 to 90 % and then saturates.

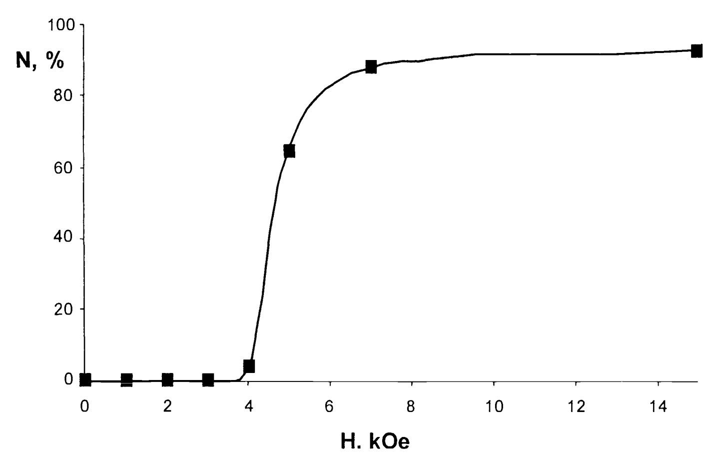


Fig. 3. The percentage N of the radial structures within the 5CB droplets ensemble as the function of magnetic field H applied during phase separation.

It should be noted that the orientation structures formed in 5CB droplets nearby H = 4 kOe are unstable. The transformation of the NLC director configuration is revealed in the flicker of the droplet textures observed in the crossed polarizers. The period of such flickers is few seconds.

In conclusion, we have studied the uniaxially oriented PDNLC films prepared by SIPS method. At that the longitudinal magnetic field was applied to the film during the phase separation. In this case the magnetic field orients a nematic inside the droplets at the time of their formation. Apparently, the LC molecules carry the macromolecules of polymer when the matrix is plastic yet. This process is completed by creation of the axis of easy orientation at the walls of the cured matrix. After the field switching off the LC director orientation corresponds to the summary minimum of the energy of elastic deformations in droplet volume and the energy of the anisotropic surface interaction of the nematic with polymer walls.

The formation of uniaxially arranged ensembles of the bipolar nematic droplets has been found when the magnetic field exceeds a certain critical value H_c. However, the SIPS method is effective not for all PDNLC films. In the some compositions, for example 5CB/PVB, the tangential boundary conditions are transformed into the homeotropic ones. At the transient surface conditions this process is accompanied by the formation of the non-equilibrium structures with the flickering textures.

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