Magnetic-Field-Assisted Formation of Alignment Polymer Coatings in Liquid Crystal Cells

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Abstract—We describe a new method for obtaining liquid crystal (LC) layers with planar orientation in plane-parallel cells, which is based on the technology of LC–polymer interface formation in solution under the action of an applied magnetic field. The azimuthal anchoring energy of LC at the polymer surface has been determined by measuring the angle of orientation of the nematic LC director on the substrate surface as a function of the magnetic field. The LC orientation provided by the proposed method is stable, and the anisotropy of LC anchoring is comparable with that achieved using well-known methods of alignment polymer film preparation by rubbing.

One of the main problems in the technology of optoelectronic devices (displays, light modulators, light shutters, etc.) based on liquid crystals (LCs) is the development of methods for the formation of a certain orientation of the LC director in optical cells. At present, this task is conventionally solved by glass substrates with polymer coatings, in which an easy alignment axis can be set by various methods, including mechanical processing (rubbing), curing in a polarized light, etc. [1]. Methods based on the interaction with an applied magnetic field are virtually not used in the modern LC cell technologies. However, there are examples of a successful use of magnetic fields for the orientation of LC-based composites. In particular, West et al. [2] patented a method for the manufacturing of composite films comprising a uniaxially oriented ensemble of LC droplets encapsulated in a polymer matrix. This orientation was achieved by heating the film to a temperature of the polymer transition to a plastic state (whereas the LC remained in the nematic phase) followed by cooling in the presence of a magnetic field that was sufficient to align the nematic LC droplets. The ensemble of LC droplets retained its orientation after switching off the field. Analogous results were obtained for an LC dispersed in a photocured polymer [3] and in poly(vinyl butyral) (PVB) according to our solution technology [4]. In the former case [3], the process of phase separation of a homogeneous LC solution in a prepolymer with the formation of nematic LC droplets took place under UV irradiation in an applied magnetic field [3]. This phenomenon was explained by the fact that the polymer at the onset of curing still possesses suffi-

ciently high plasticity and its structure can be modified in accordance with the LC orientation so that an easy alignment axis appears at the surface [3]; after switching off the magnetic field, the anisotropic surface interaction keeps the nematic LC director oriented along this axis. In our experiments [4], the LC and a polymer were dissolved in a common solvent, the evaporation of which in a magnetic field was accompanied by the formation of LC droplets oriented in a preset direction.

This Letter presents the results of an investigation of the possibility of using magnetic fields for the formation of polymer coatings setting a homogeneous orientation of LCs in plane-parallel cells.

The experiments were performed with LC cells prepared using a solution technology as schematically depicted in Fig. 1. The role of an alignment polymer was played by PVB, which is known [1] to produce a planar orientation of LCs based on alkylcyanobiphenyl derivatives. A 2% PVB solution in ethyl alcohol was applied by pouring onto glass substrates. Then, in the first variant (Fig. 1a), the solvent was evaporated until complete curing of the polymer in the presence of a magnetic field ($H^* = 2 \times 10^6$ A/m) oriented parallel to the substrate surface. Two substrates prepared in this way were assembled into a plane-parallel cell, which was filled with a nematic LC (4-n-pentyl-4'-cyanobiphenyl, 5CB). An analysis of the texture patterns typical of these cells (Fig. 2a) showed that the LC layer is separated into numerous domains with a planar (or nearly planar) orientation of the director. No correlation in the azimuthal orientation of the director was observed in the ensemble of domains. Therefore, this
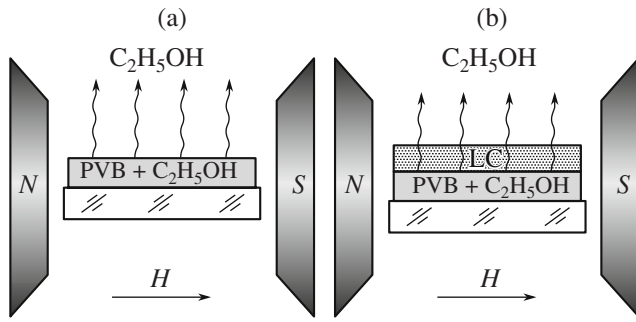
Fig. 1. Schematic diagrams illustrating the preparation of alignment polymer layers for nematic LC cells: (a) evaporation of solvent (C_2H_5OH) from PVB polymer solution in magnetic field H^*; (b) evaporation of solvent from PVB polymer through an LC layer in magnetic field H^*.
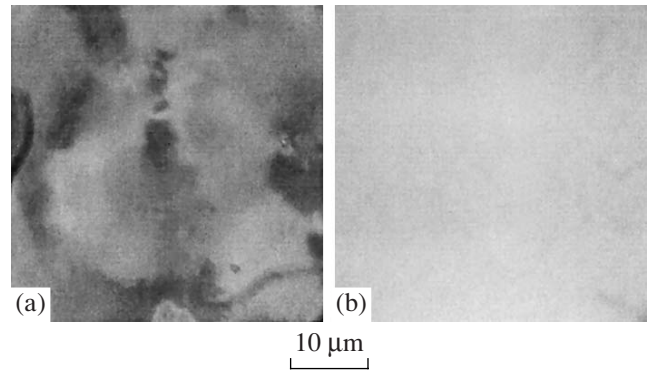

Fig. 2. Microtexture of LC layers in the nematic (5CB) LC cell: (a) inhomogeneous layer obtained using the method illustrated in Fig. 1a; (b) homogeneously oriented layer prepared using the method illustrated in Fig. 1b.

method of polymer coating preparation cannot ensure the effective formation of homogeneously oriented LC layers.

In the second variant, the polymer (PVB) was initially cured to a jelly state and then a layer of the LC (5CB) was poured (Fig. 1b). In the next stage, the solvent was completely evaporated through the LC layer in the presence of a magnetic field ($H^* = 2 \times 10^6$ A/m) oriented parallel to the substrate surface. At the beginning of this process, polymer macromolecules are sufficiently mobile and the nematic LC molecules, which are aligned in the applied field, also align the polymer molecules along the field. After switching off the field, the nematic LC layer remained homogeneously oriented in the preset direction (Fig. 2b). Observations showed that this LC orientation was retained on storage for several months.

For optical monitoring, a dichroic dye (KD-10) isomorphous to the LC was introduced into the nematic matrix at a concentration of 0.3 wt%. As is known, the introduction of dye molecules in such a small concentration does not significantly modify the properties of the LC matrix, but it leads to the appearance of an absorption band in the visible spectral range. This makes it possible to monitor of the nematic director behavior by measuring the polarized components of the optical absorption.

In order to study the anisotropic surface interaction, we have measured the azimuthal anchoring energy at the LC–polymer interface. An LC cell for this experiment was manufactured using the method illustrated in Fig. 1b. Two identical substrates were assembled so that the special directions determined by the applied magnetic field H^* would coincide. The gap between the polymer-coated substrates amounted to 30 µm and was filed with the LC (5CB). The assembled cell was placed between the poles of an electromagnet so that the lines of the reorienting field H would be parallel to the substrates and perpendicular to the nematic director n.

Laser radiation polarized in the plane parallel to H^* was transmitted through the cell at normal incidence. A change in the optical transmission $T(H)$ depending on the slowly varied reorienting field H was monitored using a photodiode.

The azimuthal anchoring energy W_φ was determined by measuring the angle φ_s of the nematic director deviation from the easy alignment axis at the LC cell surface under the action of the reorienting field H according to a method described previously [5]. The deviation angle was calculated using the following equation:

$$T = T_\parallel \cos^2\varphi_s + T_\perp \sin^2\varphi_s, \qquad (1)$$

where $T_\parallel$, $T_\perp$, and T are the transmittances of the dye soluted in the orienting nematic matrix measured for the polarization of light parallel ($\parallel$), perpendicular ($\perp$) and at an angle φ_s, respectively, relative to the director in the planar oriented LC.

In order to obtain a relationship between the angle φ_s and the anchoring energy W_φ in the case under consideration, it is necessary to consider the balance of the volume and surface torque in the LC cell. Let axis z of a Cartesian system be oriented along the normal to the polymer surface and axis x be parallel to the applied magnetic field H^*. The free energy (per unit area) of the system can be expressed as follows:

$$F = \frac{1}{2}\int_0^d \left[K_{22}\left(\frac{d\varphi}{dz}\right)^2 - \Delta\chi H^2 \sin^2\varphi \right] dz + F_{S1} + F_{S2}, \quad (2)$$

where K_{22} is the elastic modulus for the torque deformation; $\Delta\chi$ is the anisotropy of the magnetic susceptibility; d is the LC layer thickness; φ is the angle of deviation of the nematic director from the initial orientation in the volume; and F_{S1} and F_{S2} are the surface energy components of the nematic at the LC–polymer inter-

faces. For the identical substrates, the latter quantities can be expressed as follows:

$$F_S = F_{S1} = F_{S2} = F_0 + \frac{1}{2} W_\varphi \cos^2 \varphi_s, \qquad (3)$$

where F_0 is the isotropic part of the surface energy component.

A solution minimizing functional (2) is as follows:

$$\frac{d\varphi}{dz} = \sqrt{\frac{\Delta\chi}{K_{22}}} H \cos\varphi. \qquad (4)$$

The equation of equilibrium for the moments at the LC–polymer interface in the $z = 0$ plane can be written as follows:

$$K_{22}\left(\frac{d\varphi}{dz}\right)_0 - W_\varphi \sin\varphi_s \cos\varphi_s = 0. \qquad (5)$$

Combining Eqs. (4) and (5) for $\varphi \longrightarrow \varphi_s$, we obtain the following equation of torques at the surface:

$$\sqrt{K_{22}\Delta\chi} H - W_\varphi \sin\varphi_s = 0. \qquad (6)$$

Figure 3 shows the plots of $\sin\varphi_s$ versus magnetic field H for the LC cell under consideration, which were constructed using Eq. (1) for the experimental values of the transmittance (points) and theoretically calculated using Eq. (6). In the experiment, the values of $\sin\varphi_s$ were determined in magnetic fields $H < 6 \times 10^5$ A/m, for which the adiabatic theorem is valid because the magnetic coherent length is about one order of magnitude smaller than the probing laser radiation wavelength [6]. To within the experimental error, the points fit to the theoretical dependence for $K_{22} = 3.1 \times 10^{-12}$ H, $\Delta\chi = 1.19 \times 10^{-7}$ (adopted from [7, 8]) and $W_\varphi = 0.8 \times 10^{-5}$ J/m^2. This value of the azimuthal anchoring energy is close to that ($W_\varphi = 1.5 \times 10^{-5}$ J/m^2) obtained for 5CB on a poly(vinyl alcohol) surface pretreated by unidirectional rubbing [9].

Thus, we described a new method for obtaining homogeneously oriented nematic layers in a plane-parallel LC cell prepared using a solution technology in an applied magnetic field. The stability of LC orientation and the azimuthal anchoring energy are comparable with those achieved using the well-known method of polymer substrate rubbing. These results show that the proposed method has good prospects for practical implementation.
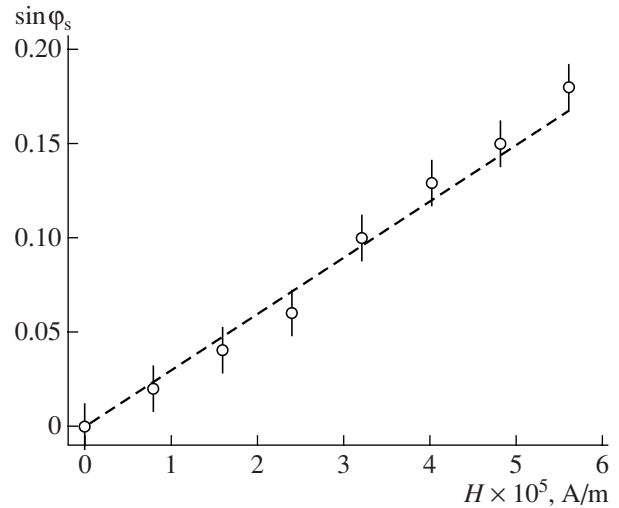
Fig. 3. The plots of $\sin\varphi_s$ for the angle of LC (5CB) director deviation from the easy alignment axis at the substrate surface versus reorienting magnetic field H: (points) experimental values; (dashed curve) calculation using Eq. (6) for $W_\varphi = 0.8 \times 10^{-5}$ J/m^2.

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