Bifunctional LCD Films

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We propose in-cell LCD films with a function of compensation films and alignment layers. The processes used to create these functions exclude mechanical contact with the films. There is proposed approach decoupling retardation and liquid crystal alignment. This approach is employed to realize different combinations of retardation and alignment properties.

Keywords: compensation film; in-cell film; ion beam alignment; liquid crystal alignment; photoalignment

1. INTRODUCTION

The compensation films, color filters and polarizers are indispensable elements of modern LCD. However, along with improving quality, these films complicate display's construction and technology. The use of pile of optical films increases thickness of LCD that often reduces their competitiveness in strong competition with OLED devices. The external disposition of optical films with regard to glass envelope of conventional LCD causes number of problems, such as mechanical damage, parallax etc. In case of flexible LCD, the external arrangement of polarizers may be ineffective at all, because of parasitical phase retardation of anisotropic polymer substrates. These problems can be avoided or strongly diminished by the "in-cell" location of optical films [1,2].

The considerable advance of in-cell technology may be caused by the use of multifunctional films. Following this approach one can reduce the overall thickness of optical films and number of overcoating

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processes associated with film damage and adhesion problem. This paper considers optical films with dual function: phase compensation and liquid crystal (LC) alignment. As the methods to induce optical anisotropy of the films we use self-organization [3–5] or light induced ordering [3–8]. The alignment of liquid crystals is generated by photo-alignment [9,10] or plasma beam alignment procedure [11,12]. These processes allowed us to realize different types of compensation films in combination with LC alignment ability.

2. EXPERIMENTAL

Polymer Films and LC Cells

We used four types of alignment materials with structural formulas presented in Figure 1:

1) PI-1, polyimide containing fluorenilidenediphenyl fragment. It is chosen taking into account that PIs with aromatic main-chain cores form negative C optical films [13].

PI-1   PI-2

in PI 2555 (Du Pont)

azo-PI   PVCN
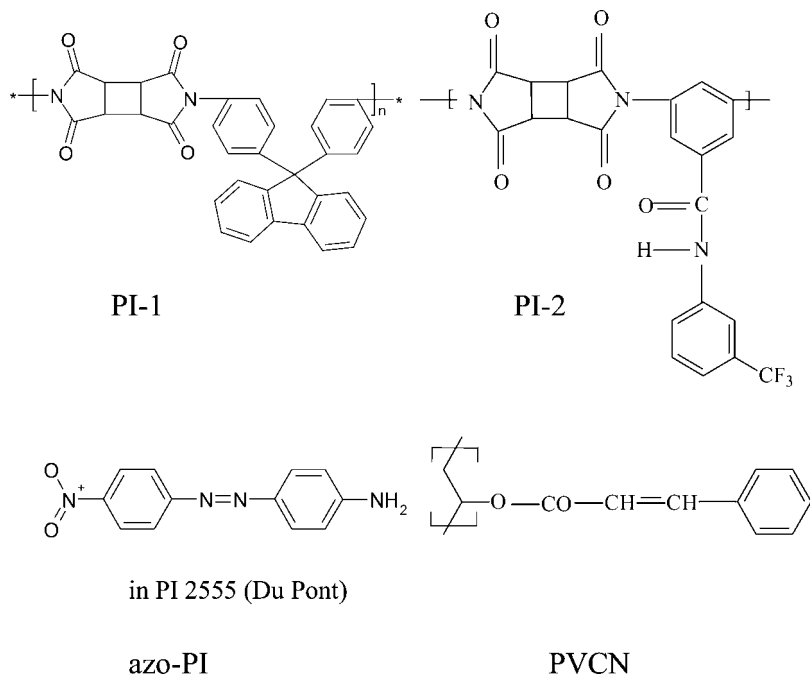
FIGURE 1 Chemical structures of polymers used for bifunctional films.

2) PI-2, polyimide with hydrophobic benzanilide fragment. As we found out before [5,14,15], hydrophobic side chains fragments tend to be aligned normally to the substrate providing optical negative C plate. The LC photoalignment properties of PI-1/PI-2 compositions have been studied in Ref. [16].

3) Azo-PI, solid solution of azo-dye Disperse Orange 3 (4-(4-nitro-phenylazo)aniline, Aldrich Chemicals) in polyimide (Du Pont PI2555). This is the classical photoalignment composition [10].

4) PVCN, polyvinylcynnamate, the other classical photoalignment material [9].

The films were obtained by spin coating of polymer solution on the glass slabs preliminarily cleaned. After that the films were backed at the appropriate temperature (PI-1, Azo-PI: 220°C, PI-2: 180°C, PVCN: 100°C) over 1.5 h. The thickness of the obtained films was in the range of 200–1000 nm.

To induce optical axis with the non-zero in-plane projection, the films were normally exposed to polarized UV light ($10.5\,mW/cm^2$) or obliquely to a non-polarized UV light ($60\,mW/cm^2$, incidence angle of $60°$) from the high-pressure mercury lamp. The irradiation was carried out stepwise to find dependence of the in-plane and out-of-plane retardations on the exposure dose.

The irradiated films were used as the LC alignment layers. Besides, for LC alignment we used polymer films subjected to particle beam alignment action. In the latter case, the substrates were etched with a plasma beam from the anode layers source directed obliquely to the alignment surface (the angle of incidence was about $70°$). Different incidence directions of plasma beam were used. The details of plasma beam alignment method can be found in our recent publications [11,12].

The LC cells were assembled from the tested substrate containing polymeric alignment layer and the reference substrate containing rubbed PI film with predetermined direction of easy axis. The director configuration in these cells allowed us to determine the easy axis direction of LC on the tested substrate. The cell gap was $25\,\mu m$. The alignment of nematic LC E7 was investigated.

Methods

The phase retardation properties of polymer films were measured by transmission null ellipsometry (TNE), which is a modified version of Senarmont method extended for the measurement of the out-of-plane retardation. The obtained retardation parameters allowed us to determine the eigen values of the refractive index n_{ij} and, consequently, the orientational configuration of aromatic fragments. For that we assume

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that directions of maximal values of n_{ij} correspond to the maximally populated directions of the anisotropic aromatic fragments. The details of this method can be found in our previous works [5,14,15].

For the UV irradiated films the retardation parameters were measured after subsequent irradiation steps. It allowed us to determine retardation properties of the films for different irradiation doses.

The easy axis direction of LC on the tested substrates was determined by observation of LC cells in polarizing microscope or in a viewing box.

3. RESULTS AND DISCUSSION

Retardation Properties of Polymer Films

The films of PI-1 and Azo-PI demonstrate properties of negative C plate ($n_z < n_x = n_y$), Figure 2. This suggests preferable in-plane alignment of aromatic cores. In turn, the films of PI-2 exhibit properties of positive C plates ($n_z > n_x = n_y$), presumably, because of out-of-plane alignment of fluorinated benzanilide fragments. Finally, films of PVCN are spatially isotropic. The observed structures are determined by the processes of molecular self-organization, which, in turn, depend on the molecular composition [3–5].

The UV irradiation causes non-essential changes of PI-1 and PI-2 films. In contrast, the retardation properties of Azo-PI and PVCN change drastically. The phase retardation parameters alter with irradiation dose showing a tendency of saturation. As an example, Figure 3 presents the plots of retardation parameters for Azo-PI film corresponding to the case of polarized light irradiation. One can see continuous transition from the negative C film before irradiation to the positive A film ($n_y > n_x = n_z$) in a saturation state. The film is biaxial in the transient states. At the same exposure conditions the PVCN layer transforms from isotropic state to the state with the properties of negative A plate ($n_x < n_y = n_z$). In case of oblique exposure with a non-polarized light the saturation state is characterized by uniaxial structure with optic axis tilted towards exposure direction (optical O film). The latter kind of anisotropic film is realized for PVCN. Thus, studied polymers allow us to realize major kinds of compensation films. The other examples of photosensitive materials for compensation films we brought in Refs. [5,14,15].

Bulk Anisotropy and LC Alignment

As discussed in Ref. [17], orientational order can be transferred from the polymer bulk to the polymer surface and then to LC layer, if this sequence is not broken at the polymer surface, e.g., because of strong
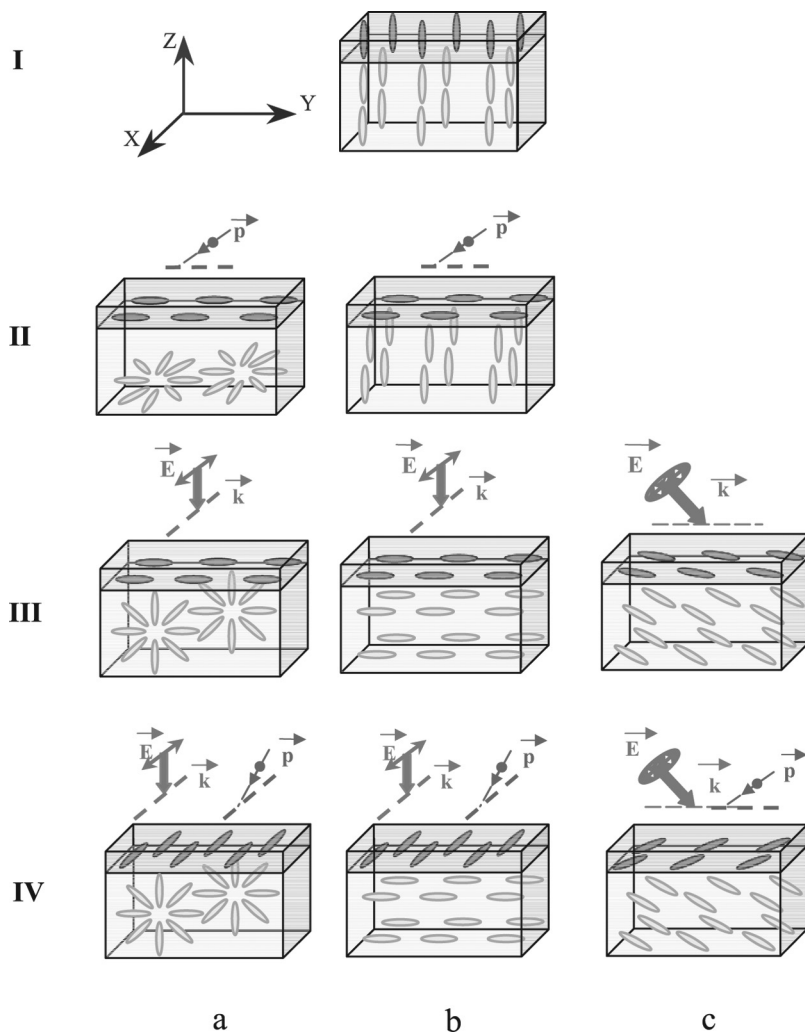
FIGURE 2 Orientational order in polymer films and liquid crystal alignment. I – untreated films of PI-2; II – plasma beam treated films of PI-1 and Azo-PI (a), PI-2 (b); III – photoirradiated films of PVCN (a), Azo-PI (b), PVCN (c); IV – photoirradiated and, subsequently, plasma beam irradiated films of PVCN (a), Azo-PI (b), PVCN (c). Irradiation geometries are schematically shown above the films. Vectors $\vec{k}$ and $\vec{p}$ define incidence direction of UV light and plasma beam, respectively.

self-assembling. In other words, orientational orders of polymer film and LC layer can be effectively coupled. The obtained results clearly demonstrate this rule.
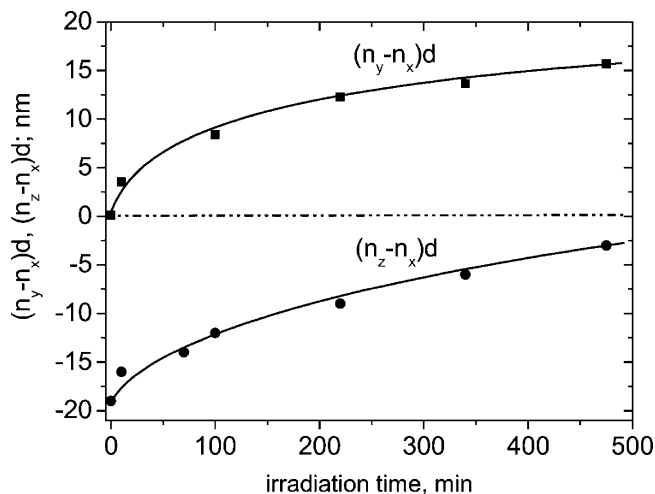
FIGURE 3 The in-plane $(n_y - n_x)d$ and out-of-plane $(n_z - n_x)d$ phase retardations caused by Azo-PI film as functions of exposure time. The film is exposed to polarized UV light $(10.5\,\text{mW/cm}^2)$ at normal incidence.

Figure 2 shows LC alignment on both untreated substrates and the substrates subjected to UV, plasma beam and UV/plasma beam treatment. Note that only examples of uniform LC alignment are given. In case of non-treated films, as well as the films subjected to UV irradiation, the LC order (direction of LC uniaxial ordering) is governed by the order of polymer film. This rule restricts combinations of polymer/LC optical films to those shown in rows I and III of Figure 2.

The variety of combinations of polymer/LC films can be infinitely extended by the use of plasma alignment technique. According to TNE results, plasma beam action does not influence anisotropic properties of polymer films (non-treated films and photoirradiated films as well). At the same time, the easy axis direction of LC is effectively governed. For demonstration, Figure 4 shows a LC cell containing PVCN alignment substrate viewed between a pair of crossed polarizers. The PVCN substrate is exposed to polarized UV light. Subsequently, part of this substrate selected with a mask is exposed to plasma beam in geometry providing reorientation of easy axis in $90°$. One can see that this reorientation is effectively realized. Thus, plasma action overcomes alignment action of UV light. This allows us to decouple orientational order of polymer and LC films and so to realize unlimited variety of film combinations. Some of them are presented in Figure 2 (rows 2 and 4). Noteworthy, the employed
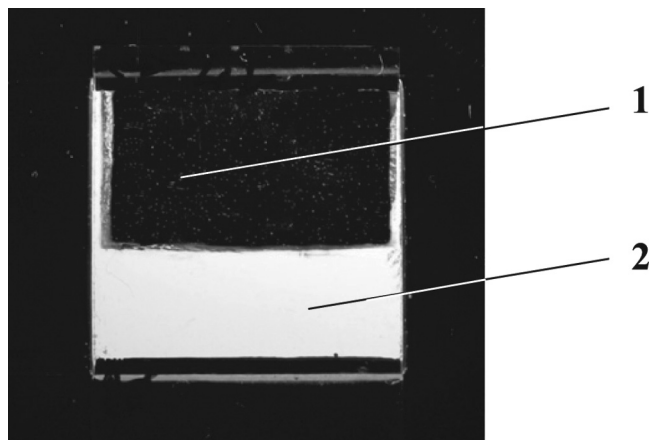
FIGURE 4 The photograph of LC cell viewed between a pair of crossed polarizers. The reference substrate is rubbed PI, while the tested substrate is PVCN. The all PVCN substrate is exposed to polarized UV light. Subsequently, the part of this substrate (part 2) is exposed to plasma beam in geometry providing reorientation of easy axis induced by UV light in 90°. It is evident that in part 2 LC alignment is determined by the plasma beam action, while in part 1 it is influenced by UV light exposure.

non-contact alignment procedures allow to pattern bulk anisotropy of the films and/or LC alignment. It is quite important that retardation and alignment function of these films can be independently varied.

Finally, the fact that plasma beam action does not destroy anisotropy of polymer films elegantly proves that active particles (ions and neutrals) bombard only top layer of solid, but do not penetrate to its bulk.

4. CONCLUSIONS

We propose new technical solution for the in-cell LCD technology based on the use of multifunctional films. To demonstrate this approach we prepared films with a dual function: phase compensation and LC alignment. By combination of UV light and plasma treatment one can vary the compensation and alignment properties independently. The compensation film and/or LC alignment can be easily patterned. In frame of this concept one can substitute some treatment process with the other one (for instance, one can replace light processing by stretching for optical anisotropy induction). The proposed approach can also be used to prepare other kinds of bifunctional films, such as polarizer/alignment films, filter/alignment films, etc.

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