Improvement of the Surface Anchoring Energy of the Photo-Alignment Layer in a Liquid Crystal Display using the Two-Band UV Exposure Method

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Abstract

In this paper, we proposed the photo-alignment method with the strong surface anchoring energy by applying the two band UV exposure method on the photosensitive PI layer embedded with reactive mesogens (RMs) for achieving the fast response time properties of the in-plane switching (IPS) LC mode. We first enhanced the interconnection between a RM polymer and a photo-alignment layer through high band ultra-violet (UV) exposure on the long pass UV filter over 340 nm and then established the alignment of LCs through low band linear polarized UV exposure at 254 nm after eliminating the UV filter. As results, we measured the surface anchoring energy and response time of the proposed photo-alignment method and also confirmed that the optical response time was reduced by approximately 22.3 % compared to that of the IPS-LC cell of pure photo-alignment layer.

Author Keywords

Photo-alignment layer; two-band ultra-violet exposure method; surface anchoring energy; optical response time; in-plane switching liquid crystal cell

1. Introduction

Today, the performance of the displaying image quality of a liquid crystal displays (LCDs) has been developed by extensively studying a variety of LC modes such as twisted nematic (TN) [1], in-plane switching (IPS) [2], fringe-field switching (FFS) [3], patterned vertical alignment (PVA) [4] and multi-domain VA (MVA) [5]. In spite of their superior optical modes, current technologies of liquid crystal displays (LCDs) are required to realize better electro-optical characteristics such as a wide viewing angle, high resolution and fast response time in order to win the competition with an organic light emitting diode (OLED) display [6-8]. Recently, the photo-aligning system which is one of non-contact alignment methods has been intensively studied for improving the displaying performance of LCDs [9]. Compared to conventional mechanical rubbing process, it is easy to orient the LC directors on the alignment layer because the chemical bondings of the photosensitive polymer layers are decomposed or isomerized along the polarization axis by exposing a linearly polarized UV light. For this reason, the various advantages over conventional rubbing of polymers, such as cleanliness, high order parameter of LCs and controllability of alignment direction could be provided. Especially, the good uniformity for large sized display panels is readily achievable through the photo-alignment processing. These features of the photo-alignment method may be suitable for achieving a better electro-optical performance in LCDs. However, the stability of anchoring energy is somewhat lower than that of the other polymer films in spite of the development of surface anchoring strength from the manufacturer so that the slow response time of LCDs can occur.

The previous paper was proposed the enhanced surface anchoring energy in a photosensitive polyimide (PI) layer [10] by using the ultra-violet (UV) curable reactive mesogens (RMs). The RM polymers within the alignment material can be strongly connected between the LCs and polymer chains so that the surface anchoring energy and order parameters of LC molecules was increased. However, they used a mixture of general polyimide materials and RMs as photosensitive alignment layer instead of the pure photo-alignment materials in previous paper. Actually, chemical bonding structure of photo-alignment materials and RM polymers are reorganized when exposing the UV light. Therefore, if a RM polymer is embedded into the photo-alignment layer for enhancing the surface anchoring energy, the chemical structures of materials are destroyed by the exposure of UV light so that we cannot obtain the good LC ordering and strong anchoring energy. Thus, study for processing method which can improve the surface anchoring energy of a photosensitive alignment layer should be absolutely performed for the high displaying performance.

In this paper, we proposed the photo-alignment method with the strong anchoring energy by applying the two-band UV exposure method on the photosensitive PI layer embedded with RMs and photo-initiators in the in-plane switching LC (IPS-LC) mode. In order to realize the strong interconnection between RM polymers and photo-alignment layer, we first exposed the UV light at the bandwidth over 340 nm on the mixed alignment layer after using the long pass UV filter. And next, we photo-aligned LC molecules to linearly polarized UV light at 254 nm. In experiments, we measured the azimuthal anchoring energy of the proposed photosensitive PI layer embedded RMs, and also demonstrated the enhanced optical response of LCs in the IPS-LC cell by comparing to other samples of a basic polymer for rubbing and a pure photosensitive PI layer.

2. Experiments

In general, the surface anchoring energy depends on the molecular interactions between LCs and the polymer chains of alignment layers; especially it is closely related to the stability and strength of the alignment layer. Therefore, it is believed that the enhanced anchoring energy can improve the LC switching behavior in dynamic conditions and the high speed switching characteristics would be achievable in a variety of LC modes.

Based on the surface dynamic equation method for the Rapini-Papoular phenomenological model, the optical response time which is defined by the summation of the rising time (τ_{on}) and falling time (τ_{off}) under applied driving voltages is strongly dependent on the surface anchoring energy (W) if W has actually finite value, as follows [11],

$$\tau_{on} = \frac{\gamma}{\left|\varepsilon_0\right|\Delta\varepsilon\left|E^2 - \frac{2W}{d}\right|}, \quad \tau_{off} = \frac{\gamma d}{\left(\frac{Wd}{K_{22}} + 2\right)W} \approx \frac{\gamma d}{2W} \qquad (1)$$

where, γ is the rotational viscosity, K_{22} represents the twist elastic constant, $\varepsilon_0 \Delta\varepsilon E^2$ is the electric field energy density, $\Delta\varepsilon$ is the LC dielectric anisotropy, and d is the cell gap of the LC layer. From the equation (1), the τ_{on} and τ_{off} of the LC cell are inversely proportional to the surface anchoring energy W, so that we can expect that the response time can be reduced by increasing the azimuthal anchoring energy.

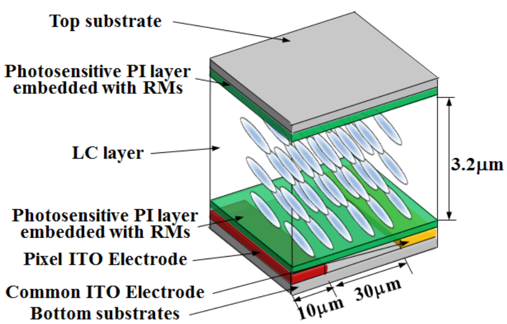

Figure 1. Schematic diagram of the modeled optical configuration of an IPS LC cell for experiments

Figure 1 illustrates the modeled optical configuration of an IPS-LC cell for experiments. In case of the electrode structure of the IPS-LC cell, the width of indium-tin-oxide (ITO) electrode which consists of common and pixel ITO electrode, and interval between electrodes are respectively set to 10 µm and 30 µm on the bottom substrate, and the top substrate had no electrode layer. The cell thickness of a LC layer of two samples is set to 3.2 µm. Samples are set between crossed polarizers, and the LC material with positive dielectric anisotropy was used. The used LC material is MLC-7037, which was made by Merck, ($\Delta\varepsilon = 5$, $\Delta n = 0.1144$, $K_{11} = 12.3$ pN, $K_{22} = 6$ pN, and $K_{33} = 13.25$ pN).

Figure 2 shows the schematic diagrams of the proposed photo-alignment process using the multi-bandwidth UV exposure system. We first prepared a top and bottom indium-tin-oxide (ITO) substrates with electrode pattern in Fig. 2(a). Top substrate had no ITO electrode layer. In case of the bottom substrate, width of ITO electrode which consists of common and pixel ITO electrode, and interval between electrodes are 10 µm and 30 µm, respectively. Before performing the spin-coating process, the RM257 (Merck, Germany) and a photo-initiator (Ciba, Darocur TPO) were mixed to a ratio of 4.2 : 0.05 wt% within the photo-sensitive PI materials (RN-1322 made by Nissan chemical co. in Japan), which is photo-decomposition type at 254 nm wavelength in Fig. 2(b), and then we stirred a mixture at 80°C for 1 hour. In case of the photo-initiators which help the efficient curing of RM monomers, we found that the dominant absorption wavelength of UV light was approached over 360 nm to avoid the chemical reaction between the RM polymers and photo-alignment layer. Next, a mixture was spin-coated on two prepared substrates at the rate of 1100 rpm for 15 sec, and then 4000 rpm for 45 sec. It was pre-baked at 80 °C for 5 min, followed by hard baking at 230 °C for 20 min for the polyimidization to occur. For enhancing the chemical interaction between RM monomers and photo-initiators in a mixture, we performed the high-band UV exposure for 80 sec at 15mW/cm^2 on the long pass UV filter over 340 nm in Fig. 2(c) and next, established the orientation of LCs on the alignment layer by exposing the low-band linear polarized UV light after eliminating the long pass filter as shown in Fig. 2(d). Due to the multi-band system in the fabrication process, we achieved the strong anchoring energy and good LC ordering on photo-alignment layer without any destruction of chemical bonding structure. Finally, two substrates were assembled to parallel type structure with a cell gap of 3.2 µm and then, the LC material was injected into the cell layer in Fig. 2(e).

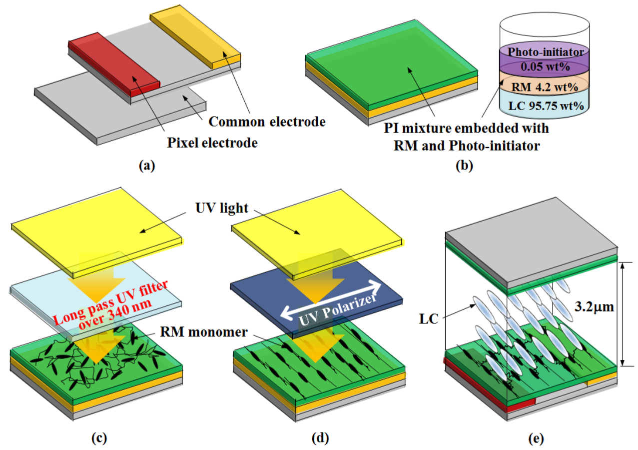

Figure 2. Schematic diagram of the fabrication process for achieving the strong anchoring energy of a photo-alignment layer.

3. Results and Discussions

Figure 3 shows the measured azimuthal anchoring energy for three types of alignment sample: a basic polymer films for mechanical rubbing, a pure photo-sensitive polymer materials, and a proposed photo-sensitive polymer embedded with RMs as a function of the actual twist angle ϕ_t. The azimuthal anchoring strength (A) was measured in twisted nematic (TN) LC cell by using the torque balance method as following expressions [12]:

$$A = \frac{2K_{22} \times \left\{\phi_t - \left(2\pi \times \frac{d}{p}\right)\right\}}{d \times \sin(2\Delta\phi)}, \quad \phi_t = \phi_r - 2\Delta\phi \qquad (2)$$

where, ϕ_r is the angle between two alignment angles, ϕ_t is the actual twist angle related to ϕ_r and $\Delta\phi$, and p is the LC's pitch. In experiments, the value of the alignment angle ϕ_r and pitch p was set to 30° and 12 µm. Three curves in Fig. 3 represent the relationship between the azimuthal anchoring strength and the ϕ_t

if the cell gap is 2.7 μm, 3.2 μm, and 3.7 μm, respectively. As a measured result, actual twist angles for two samples of the basic polymer for rubbing and a pure photo-alignment material were stayed between the 39.5° and 42.5°, respectively so that we achieved that the azimuthal anchoring energy shows the average value of 1.789×10^{-5} J/m^2 on the basic polymer layer for rubbing and 1.887×10^{-5} J/m^2 on pure photo-alignment layer. However, after mixed the RMs and photo-initiators within photosensitive PI layer, the azimuthal anchoring energy was measured to the average value of 4.581×10^{-5} J/m^2 at twisted angle of 35°, and it was about 2.5 times higher than that of other two samples because photo-polymerized RMs within the photo-alignment layer induced the strong interaction with the LC molecules.

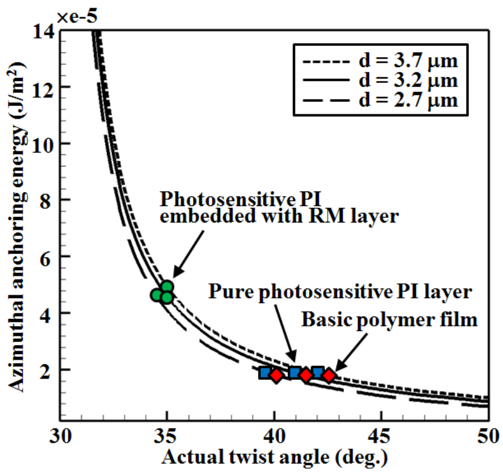

Figure 3. Comparison of the measured surface anchoring energy for three alignment sample: a polymer films for mechanical rubbing, a pure photosensitive polymer materials and a proposed photosensitive polymer embedded with RMs.

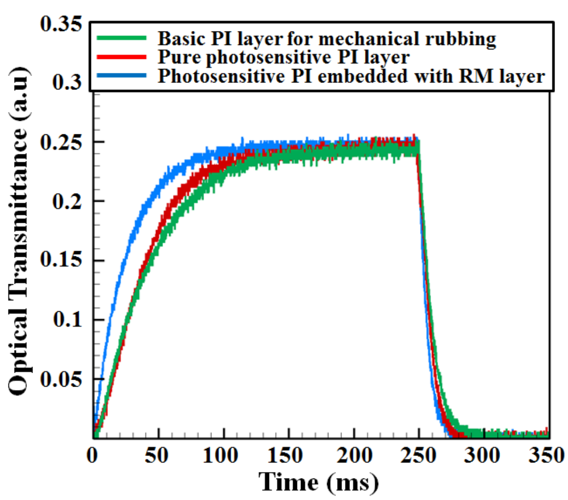

Figure 4. The calculated optical response time of an IPS LC cell for three alignment samples: a polymer films for mechanical rubbing, a pure photosensitive polymer materials and a proposed photosensitive polymer embedded with RMs.

We investigated the dependence of the optical response time of an IPS LC cell on the azimuthal anchoring energy in experiments. Figure 6 compared the measured optical response time on the proposed photosensitive PI layer with two samples of the basic polymer for rubbing and a pure photosensitive PI layer in the IPS LC cell. We observed that the rising time and falling time of two samples with relatively weak anchoring energy were measured to 69.34 ms and 17.14 ms at 13 V on rubbing layer and 58.79 ms and 14.09 ms at 15 V on a pure photosensitive PI layer, respectively. The proposed method was measured to 45.89 ms in rising time and 10.71 ms in falling time under applied 16.5 V. Consequently, total response of an IPS LC cell was reduced by approximately 22.3 % compared to that of a sample with the pure photo-sensitive PI layer so thus, we demonstrated the fast response time of the IPS LC cell on the photosensitive alignment layer due to the strong anchoring energy.

As measured results, we successfully obtained the strong anchoring energy in the photo-alignment method by embedding the RM polymers and the photo-initiator and demonstrated that the dynamic optical response time is strongly influenced by azimuthal anchoring energy in the experiments.

4. Conclusion

In summary, we enhanced anchoring energy on the photo-sensitive PI layer with an embedded the RMs by using the double UV exposure method with a separated bandwidth. In experiments, we achieved the strong anchoring energy in the proposed photo-alignment method and demonstrated that the dynamic optical response of an IPS LC mode is strongly sensitive to the surface anchoring energy. As a result, we successfully achieved that the surface anchoring energy and optical response time were improved by approximately 2.5 times and 22.3 % compared to that of the conventional photo-alignment cell, respectively. Obviously, the photo-alignment method is one of the most important factors for high image quality of the LCD devices and thus, we believed that the proposed photo-alignment method which can improve the surface anchoring energy will be contributed to the development of electro-optical performance of LCDs.

5. Acknowledgements

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