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Fast response time of liquid crystal display modes using band separation UV exposure method

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ABSTRACT

We propose a double frequency ultraviolet (UV) exposure process that can improve the surface anchoring energy of photopolyimide (PI) embedded with reactive mesogens (RMs) for the high speed liquid crystal modes. In experiment, we polymerize the RM materials using long wavelength UV light over 340 nm, and then accomplish the polymerization of the UV alignment layer using short UV light between 254 nm and 340 nm. As results, we demonstrate the improved surface anchoring energy and the fast response time of an in-plane switching (IPS) and a twisted nematic (TN) LC modes in this paper.

KEYWORDS

Surface anchoring energy; in-plane switching; twisted nematic; reactive mesogen; response time; photoalignment

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 [1–5]. In spite of their superior optical modes, studies of advanced technologies of LCD devices are still required to improve the display performances including the brightness, resolution, viewing angles and response time in order to maintain competition superiority compared with other display devices, e.g., organic light emitting diode (OLED) displays. Especially, fast response time is major important factor for high displaying performance because slow speed property of LCD device can induce the motion blurs and the color break up, and crosstalk in applications for virtual three-dimensional images.

In general, the optical response time of LCDs is defined as the sum of the rising time (τ_{on}) and falling time (τ_{off}). In particular, the falling time is more important than the rising time in current display devices because the falling time of LC response is only dependent on LC material properties. The response time of the homogeneous photoaligned LC modes can be calculated using [6, 7]

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

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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, d is the cell gap of the LC layer, and W is the surface anchoring energy.

From the Eq. (1), low cell gap, small viscosity and elastic constant of the LC material was studied in the previous paper for obtaining the fast response time property. However, current study is focused on the surface anchoring energy of alignment layer because the strong anchoring energy can strongly affect the dynamic behavior of LC molecules on the surface [6, 8]. For high surface anchoring energy, reactive mesogens (RMs), which are polymerizable LCs, are used in typical photopolyimide (PI) layers in recent study [7, 9]. The RMs mixed with a photoinitiator can provide a rigid polymer network by interconnecting the molecules with the PI material under ultraviolet (UV) exposure. Consequently, the crosslinked polymer chains between the PI and the RMs can effectively improve the surface anchoring power of typical PI layers.

However, recent alignment technology of LCD devices has rapidly changed to the UV exposure method, which is a representative of the noncontact type, instead of the mechanical rubbing process. It is easy to orient the LC molecules on the alignment layer along the polarization axis by exposing the linearly polarized UV light because the chemical bondings of the PI layers are decomposed or isomerized. Thus, the various advantages such as cleanliness, high order parameter and zero pretilt angle of LCs and controllability of alignment direction could be shown. However, in case of the photoalignment layer, the separation of the polymerization for the RM and PI materials is needed to achieve the high surface anchoring energy because the functional chemical roles of RM and PI are different.

In this paper, we propose a photoalignment method that can achieve the strong surface anchoring force to double friquency UV exposure by using two UV light sources on the PI layer embedded with RM for the fast response time property of the homogeneously aligned LCD modes. The process of the proposed method starts to polymerize the RM using long wavelength UV light over 340 nm and then, accomplish the polymerization of the photoalignment layer using short UV light between 254 nm and 340 nm. In the experiments, we observed high surface anchoring power of the PI layer embedded with RM, and demonstrated the fast response time of the homogeneously aligned LCD modes especially, IPS LC cell and TN LC cell.

2. Experiments

In general, to increase anchoring power of the PI layer, more rigid polymer network structures in the PI layer are required. As pointed out in the Introduction, the functional chemical roles of the embedded RM and the PI layer for the polymerization are different so that we need to separate the polymerization process of two target materials to avoid the deterioration of the alignment function of the PI material during the polymerization process of the RM material.

Figure 1 shows the schematic diagrams of the polymerization process for achieving the strong anchoring energy of LC cells by using the double frequency UV exposure. First, we prepared top and bottom substrates coated to indium–tin–oxide (ITO) electrode. Then, we set an experimental reference condition for the mixture of the PI material (RN-1322, Nissan Chemical Co., Japan) and RM257 monomer (Merck, Germany) with photoinitiators (Ciba, Darocur 1173) to a ratio of 95.75:4.25 wt%. The wavelength of the UV light for photodecomposition of the PI layer was 254 nm. Then, the mixture was spin-coated on two prepared substrates at a rate of 1100 rpm for 15 s and then 4000 rpm for 45 s, as shown in Fig. 1(a).

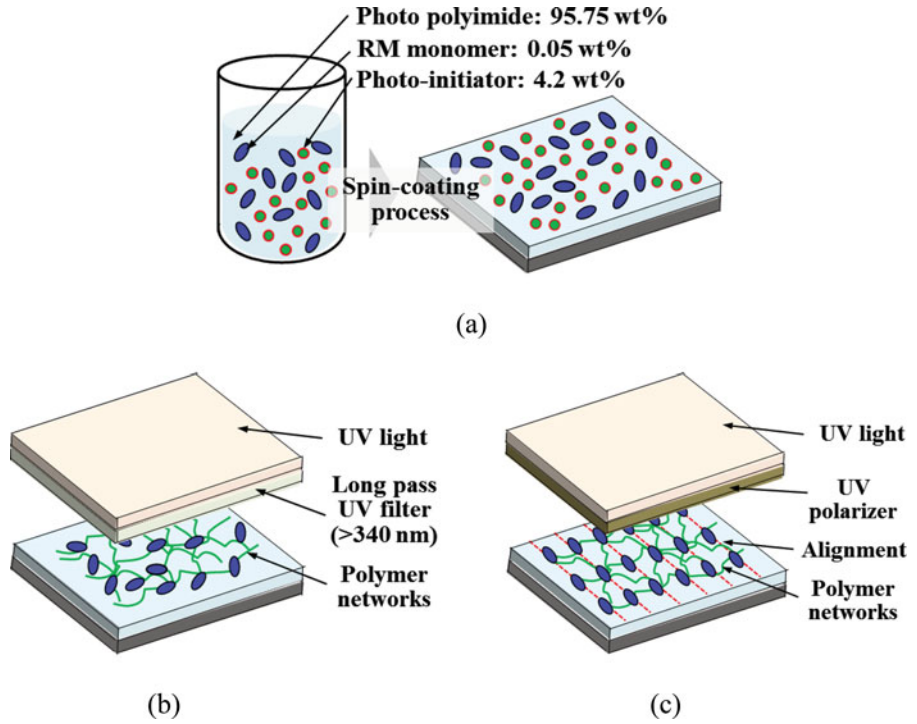

Figure 1. Fabrication process of the band separation UV exposure method for achieving the strong anchoring energy of the PI layer. (a) Spin-coated mixture of the PI material and RM, (b) long wavelength UV exposure for the polymerization of RM, and (c) the short wavelength UV exposure for the alignment of the PI layer.

After the spin-coating, it was prebaked at 80°C for 5 min, followed by hard baking at 230°C for 20 min for poly-imidization. To perform the polymerization process for the rigid polymer network and high-order parameter properties in the PI layer, we starts to polymerize the RM to long wavelength UV light for 80 sec at 15mW/cm^2 by using the long pass UV filter over 340 nm in Fig. 1(b) and then, accomplish the polymerization of the photoalignment layer by exposing the short UV light between 254 nm and 340 nm after eliminated the UV filter as shown in Fig. 1(c). Two UV light source are successfully polymerized for the embedded RM and the PI layer without any destruction of their chemical compositions. Finally, the two prepared substrates were assembled with a cell thickness of 3.2 μm and then the LC material (MLC-7037, $\Delta\varepsilon = 5$, $\Delta n = 0.1144$, $K_{11} = 12.3$ pN, $K_{22} = 6$ pN, and $K_{33} = 13.25$ pN, Merck) was injected into the cell layer.

3. Results and discussions

Figure 2 shows the measured surface anchoring energy of the PI layer embedded with RM for three alignment layer: a polyimide layer by mechanical rubbing process, a typical PI layer, and a proposed PI layer embedded with RM. The surface anchoring energy (W) was determined by measuring the actual twist angle (ϕ_t) of a TN LC cell using the torque balance method as follow [10]:

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

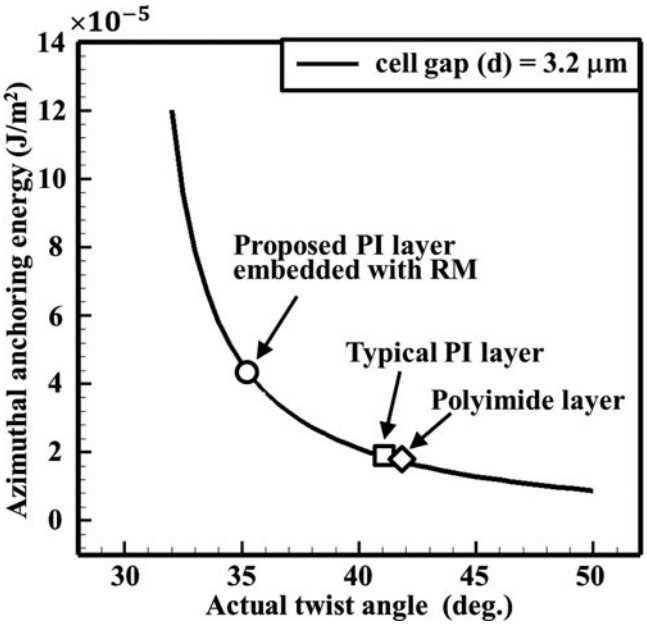

Figure 2. Measured surface anchoring energy for three alignment conditions: the polyimide layer by rubbing process, the typical PI layer, and the proposed PI layer embedded with RM.

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. The black solid line in the Fig. 2 represents the fit curves for the actual twist angle as a function of anchoring energy for 3.2 μm cell gaps, respectively. We can see that actual twist angle of the polyimide layer (JSR, AL1630K) for rubbing process and the typical PI layer stayed between 42.5° and 39.5°, respectively, so that the value of the azimuthal anchoring energy was calculated as 1.789×10^{-5} J/m^2 on the rubbed polyimide layer and 1.887×10^{-5} J/m^2 on the typical PI layer, respectively. However, after embedding the RMs and photo-initiators in the PI layer, the surface anchoring energy was calculated to the average value of 4.581×10^{-5} J/m^2 as the measured twist angle ϕ_t decreased to 35°. Therefore, the anchoring energy on the PI layer embedded with RM of the cell could be improved by approximately 2.5 times, compared with typical PI layer, thus giving rise to a fast response time of the LC cell.

In order to demonstrate the effect of the surface anchoring energy, we measured the optical response time of a TN and an IPS LC modes on three polyimide layers. Figure 3(a) and 3(b) illustrate the modeled optical configuration of the TN mode and the IPS LC mode. In case of the electrode structure of the IPS LC cell in Fig. 3(b), the width and the interval of the common and the pixel electrode are respectively set to 10 μm and 30 μm on the bottom substrate.

In order to exactly compare the optical response time of each polyimide layer, we first investigated the appropriate driving voltage depending on three polyimide conditions by using voltage-transmittance (V-T) curve as shown in Fig. 4(a) and 4(b). Here, the experiment conditions used cell parameters as mentioned in Fig. 3. In the TN LC cell in Fig. 4(a), the minimum transmittance was reached at 2 V on polyimide layer for rubbing process, at 3 V on the typical PI layer, and at 5 V on the proposed PI layer embedded with RM, respectively. In the IPS LC cell in Fig. 4(b), maximum transmittance was reached at 12.9 V on polyimide layer for rubbing process, at 15 V on the typical PI layer, and at 16.5 V on the proposed PI layer

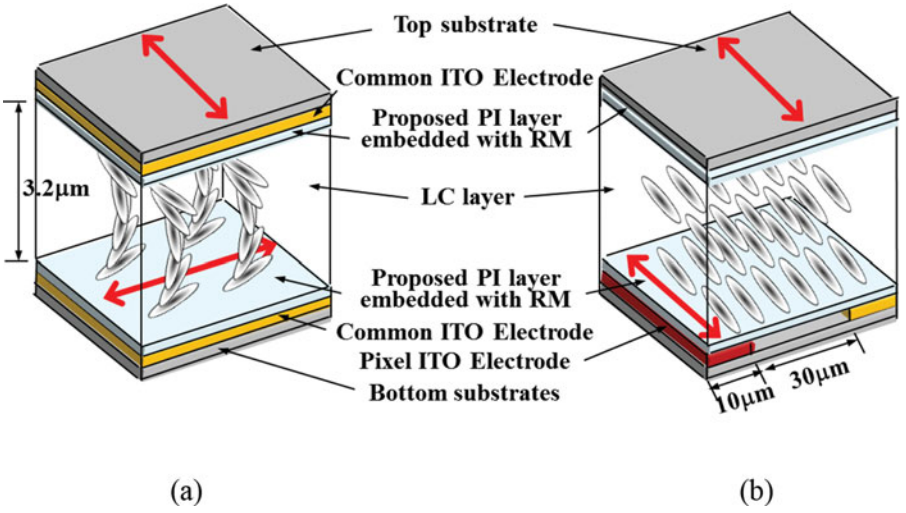

Figure 3. Modeled optical configuration of (a) the TN LC cell and (b) the IPS LC cell for experiments.

embedded with RM, respectively. As measured results, we could know that the driving voltage of LC cell are sensitive to variations for the surface anchoring strength of the polyimide layer and finally decide the appropriate driving voltage of two LC cell for three polyimide layer.

Figure 5 compared the measured optical response time on the proposed PI layer embedded with RM material with two samples of the polyimide layer and the typical PI layer in the TN LC mode and the IPS LC mode. In case of the polyimide layer and typical PI layer, the rising time and falling time were respectively measured to 7.769 ms and 14.802 ms in TN LC mode, and 69.34 ms and 17.14 ms in IPS LC mode on the polyimide layer, and also 4.551 ms and 9.368 ms in the TN LC mode, and 58.79 ms and 14.09 ms in the IPS LC mode on the typical PI layer. However, the proposed PI layer embedded with RM materials provides the rising and falling time of 3.103 ms and 7.013 ms in the TN LC mode, and 45.89 ms and 10.71 ms in the IPS LC mode. Consequently, the total response of the TN LC mode and the IPS LC mode were

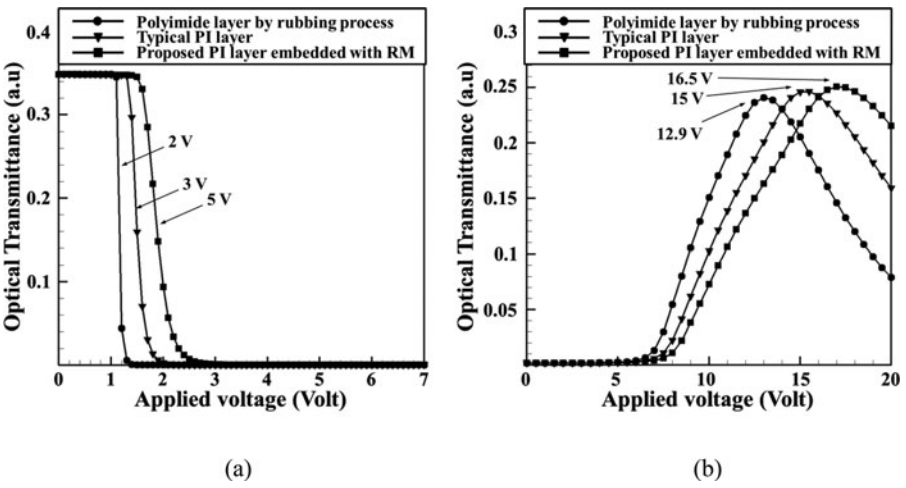

Figure 4. The measured voltage-transmittance (V-T) characteristics of (a) the TN LC mode and (b) IPS LC mode for optimizing the driving voltage depending on three alignment conditions: the polyimide layer by rubbing process, the typical PI layer, and the proposed PI layer embedded with RM.

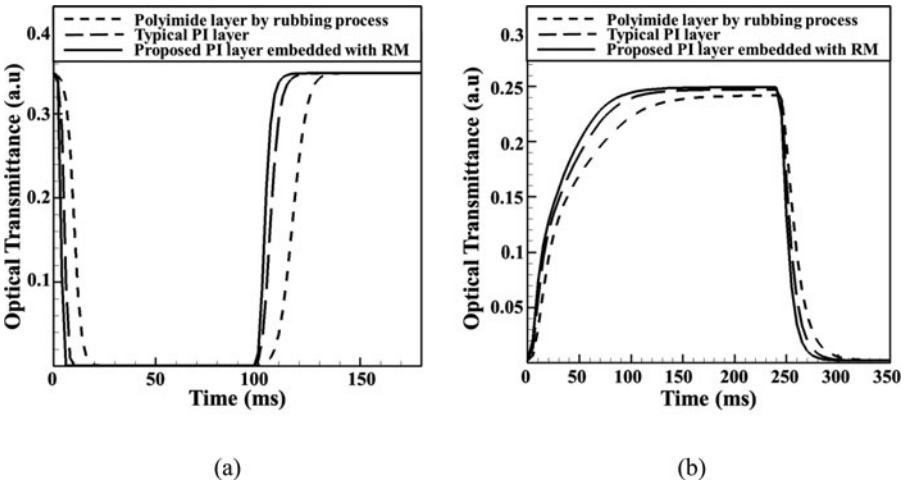

Figure 5. The measured response time of (a) the TN LC mode and (b) IPS LC mode depending on three alignment conditions: the polyimide layer by rubbing process, the typical PI layer, and the proposed PI layer embedded with RM.

respectively improved by approximately 27.32% and 22.3% compared with the typical PI layer. As measured result show, we successfully achieved the high surface anchoring energy in the typical PI layer embedded with RM polymers by using the double frequency UV exposure method, and also demonstrated the fast response time of the TN LC mode and the IPS LC mode.

4. Conclusion

In summary, we improved the surface anchoring energy on the PI layer by embedding the RMs and photo-initiators to the double frequency UV exposure. To demonstrate the enhancement of the surface anchoring power to the proposed UV exposure on the PI layer embedded with RM, we compared the measured surface anchoring energy on the three alignment layers: a polyimide layer, a typical PI layer, and the proposed PI layer embedded with RM, and also demonstrated the optical response time of the TN LC mode and the IPS LC mode. As results, we confirmed that the surface anchoring energy was increased by 2 times and the optical response time was respectively improved by 27.32% in TN LC mode and 22.3% in the IPS LC mode because of the strong surface anchoring power. We believe that the proposed UV exposure method can help in improving the electrooptical properties of LCD devices and enhancing display performance compared with other display devices.

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