Two-Band Photo-alignment Method for High Speed Twisted Nematic Liquid Crystal Cell

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ABSTRACT

We proposed the high speed twisted nematic (TN) liquid crystal (LC) cell on the photosensitive polyimide (PI) embedded with reactive mesogens (RMs) by applying two-bend separated UV exposure method. Demonstration for electro-optical properties is performed by experiments and we finally confirmed the enhanced response time of photo-aligned TN LC cell.

1. INTRODUCTION

Over time, the displaying image quality of 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]. Despite the superior optical modes, current technologies for LCD devices still need to improve the display performance, including brightness, resolution, viewing angles, and response time, in order to overcome the competition with an organic light emitting diode (OLED) display. Fast response time is one of the most important factors because slow response time of the LCD can induce motion blur and color break-up. Recently, the photo-aligning system which is one of non-contact alignment methods has been studied for improving the displaying performance of LCDs [6-9]. Compared to conventional mechanical rubbing process, it is easy to orient the LC directors on the alignment layer because the chemical bonding 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. These features of the photo-alignment method may be suitable for achieving a better electro-optical performance in LCDs. However, the anchoring power of the photo-sensitive PI layer still needs to be strong in order to achieve a fast response time, which is a weak optical point compared to an OLED.

In this paper, we propose a high speed TN LC cell by enhancing the surface anchoring energy on the photo-sensitive PI layer using the separated bandwidth UV exposure method. The proposed UV exposure method is divided into double UV exposure steps. The first step is the photo-polymerization of the embedded RM molecules within photo-sensitive PI layer by exposing them to long wavelength UV rays over 340 nm, and the second step is to create the ordered photo-sensitive alignment layer by exposing the embedded RM molecules to short wavelength UV rays between 254 nm and 340 nm. Enhanced surface anchoring energy of fabricated TN LC cell is demonstrated by torque balance method. We finally measured the optical response time of the TN LC cell and also compared the method used in this paper with a conventional UV exposure method.

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 [10],

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

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 illustrates the modeled optical configuration of a TN LC cell for experiments. The top and bottom substrates have common indium-tin-oxide (ITO) electrode layer. The cell thickness of a LC layer of 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, Δn = 0.1144, K_{11} = 12.3 pN, K_{22} = 6 pN, and K_{33} = 13.25 pN).

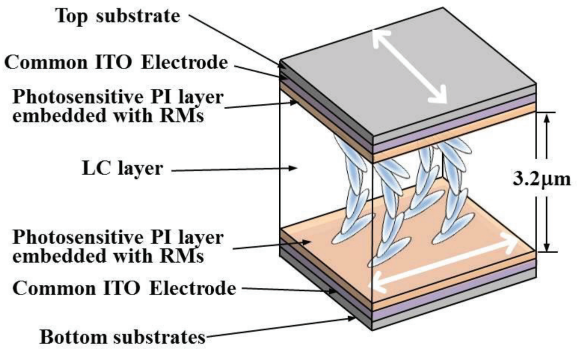


Fig. 1 The modeled optical configuration of the TN LC cell for experiments

Figure 2 shows the schematic diagrams of the proposed photo-alignment process using the two-band UV exposure system. We first prepared a top and bottom indium-tin-oxide (ITO) substrates with common electrode pattern in Fig. 2(a). Before performing the spin-coating process, the RM257 (Merck, Germany) and a photo-initiator (Ciba, Darocur TPO) were mixed to a ratio of 0.05 : 4.2 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 70°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 proposed two-band UV exposure 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).

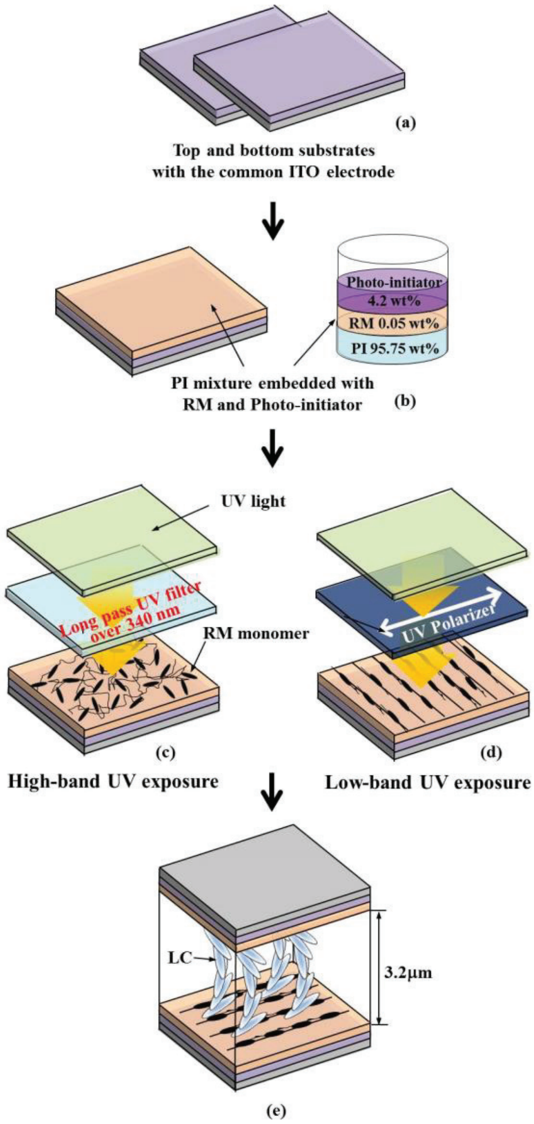


Fig. 2 Schematic diagram of the fabrication process of the proposed two-bend UV exposure system for enhancing the surface anchoring energy of the photo-sensitive PI layer

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 [11]:

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

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 3.2 μm. 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.

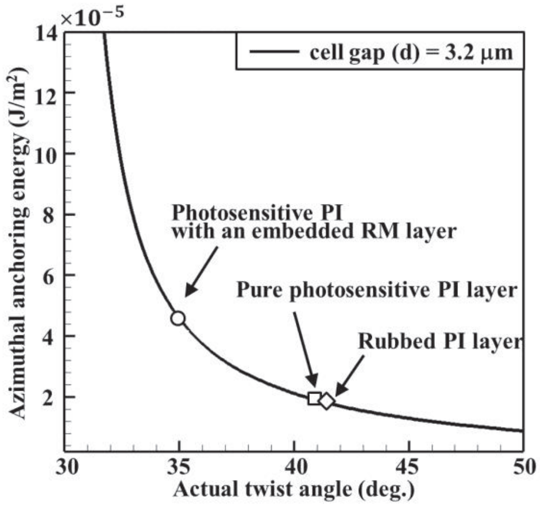
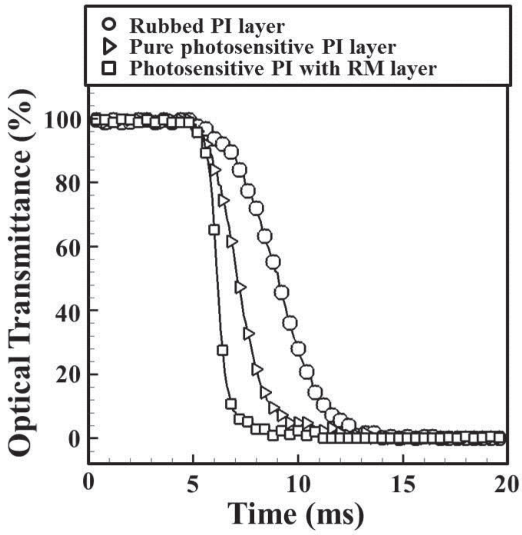
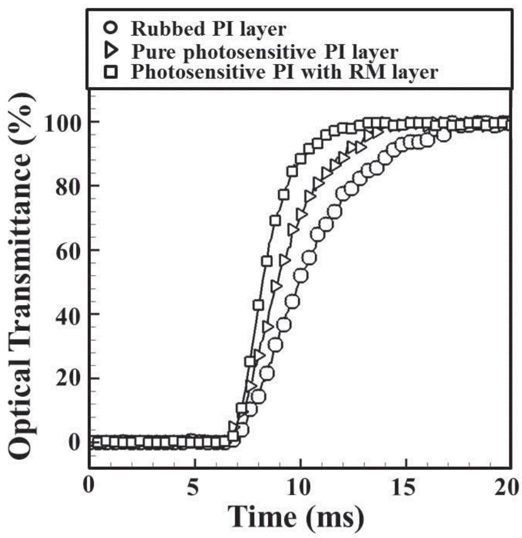


Fig. 3 Comparison of the measured surface anchoring energy for three PI samples: the rubbed PI layer, the pure photo-sensitive PI layer and the proposed photo-sensitive Pi with an embedded RM layer

We investigated the dependence of the optical response time of the TN LC cell on the azimuthal anchoring energy in experiments. Figure 4 compared the measured rising time and falling time on the proposed photosensitive PI layer with two samples of the basic polymer for rubbing and a pure photosensitive PI layer in the TN LC cell. We observed that the rising time and falling time of two samples with relatively weak anchoring energy were measured to 5.44 ms and 8.74 ms at 2V on rubbing layer and 2.71 ms and 5.09 ms at 3 V on a pure photosensitive PI layer, respectively. The proposed method was measured to 1.23 ms in rising time and 3.03 ms in falling time under applied 5 V. Consequently, total response of the TN LC cell was reduced by approximately 35.32 % compared to that of a sample with the pure photo-sensitive PI layer so thus, we demonstrated the fast response time of the TN LC cell on the photosensitive alignment layer due to the strong anchoring energy.



(a)



(b)

Fig. 4 The measured (a) rising time and (b) falling time of the TN LC cell for three PI samples: the rubbed PI layer, the pure photo-sensitive PI layer

and the proposed photo-sensitive PI with an embedded RM layer

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 CONCLUSIONS

In summary, we enhanced anchoring energy on the photo-sensitive PI layer with an embedded the RMs by using the two-bend UV exposure system. In experiments, we achieved the strong anchoring energy in the proposed photo-alignment method and demonstrated that the dynamic optical response of the TN 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 35.32 % 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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REFERENCES

[1] M. Schadt, and W. Helfrich, “Voltage-dependent optical activity of a twisted nematic liquid crystal,” Appl. Phys. Lett., Vol. 18, 127-128 (1971).

[2] M. Oh-e, and K. Kondo, “Electro-optical characteristics and switching behavior of the in-plane switching mode,” Appl. Phys. Lett., 67, 3895-3897 (1995).

[3] S. H. lee, S. L .lee, and H. Y. Kim, “Electro-optic characteristics and switching principle of a nematic liquid crystal cell controlled by fringe-field switching,” Appl. Phys. Lett., Vol. 73, 2881-2883 (1998).

[4] S. G. Kim, S. M. Kim, Y. S. Kim, H. K. Lee, S. H. Lee, G.-D. Lee, J.-J. Lyu, and K. H. Kim, “Stabilization of the liquid crystal director in the patterned vertical alignment mode through formation of pretilt angle by reactive mesogen,” Appl. Phys. Lett., Vol. 90, 261910 (2007).

[5] A. Takeda, S. Kataoka, T. Sasaki, H. Chida, H. Tsuda, K. Ohmuro, T. Sasabayashi, Y. Koike, and K. Okamoto, “A super-high image quality multi-domain vertical alignment LCD by new rubbing-less technology,” SID Dig, Tech. Papers Vol. 29, 1077-1080 (1998).

[6] B.-J. Mun, T. Y. Jin, G.-D. Lee, Y. J. Lim and S. H. Lee, “Optical approach to improve the gamma curve in a vertical-alignment liquid-crystal cell,” Opt. Lett. Vol. 38, 799-801 (2013).

[7] J.-H. Lee, J.-H. Son, S.-W. Choi, W.-R. Lee, K.-M. Kim, J. S. Yang, J. C. Kim, H. Choi and G.-D. Lee, “Compensation for phase dispersion in horizontal-switching liquid crystal cell for improved viewing angle,” J. Phys. D: Appl. Phys. Vol. 39, 5143-5148 (2006).

[8] W. S. Kang, J.-W. Moon and G.-D. Lee, “Retardation free in-plane switching liquid crystal display with high speed and wide-view angle,” J.Opt. Soc. Korea 15, 161-167 (2011).

[9] H. G. Galabova, D. W. Allender, and J. Chen, “Orientation and surface anchoring of nematic liquid crystals on linearly polymerized photopolymers,” Phys. Rev. Vol. E 55, 1627-1631 (1997).

[10] X. Nie, R. Lu, H. Xianyu, T. X. Wu, and S.-T. Wu, “Anchoring energy and cell gap effects on liquid crystal response time,” J. Appl. Phys. Vol. 101, 103110 (2007).

[11] M. Jiang, Z. Wang, R. Sun, K. Ma, R. Ma, and X. Huang, “Method of studying surface torsional anchoring of nematic liquid crystal,” Jpn. J. Appl. Phys., Vol. 33, L 1242-L1244 (1994).