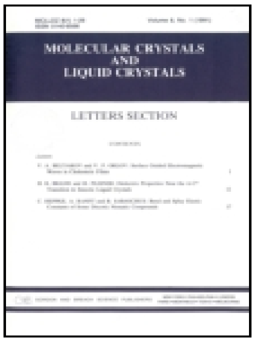

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High Speed In-Plane Switching Liquid Crystal Cell by Using Photo Alignment Method

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We proposed a fast response time in-plane swithcing (IPS) liquid cryatal (LC) mode in the photo-alignment layer. In order to achieve the fast response time, we first enhanced the anchoring energy of the photo-alignment layer by coating the reactive mesogens (RMs) which can modify the surface condition and also applied the low cell property in the LC cell by using the positive A*-plate with same effective retardation as the LC layer. In the experiments, we demonstrated that the coated RM layer can make the strong surface anchoring energy because of its strong polymer chain by the UV exposure and also confirmed the improved response time in the low cell gap IPS cell. As measured results, the response time of the proposed IPS LC cell could be improved over 56.86% and 62.18% compared with that of a conventional photo-aligned IPS cell with/without RM coating, respectively because of the low cell gap property.*

Keywords In-plane switching liquid crystal mode; Photo-alignment method; Retardation free effect; High speed response time; High image quality

1. Introduction

Liquid crystal displays (LCDs) have been widely used in various applications such as mobile phones, tablet personal computers (PCs), monitors, and televisions (TVs), because of its superior electro-optical performances including high transmittance, high resolution and wide viewing angle characteristics. Especially, one of technologies for high image quality of LC applications is uniform alignment method. Previously, many alignment methods have been proposed to obtain the uniform alignment of LCs [1–4]. Among these methods, rubbing method is the most widely used and provides the superior electro-optical performance of LC switching [5, 6]. However, contact type alignment method causes the electrostatic charges and mechanical damages so that deterioration of the image quality can occur. Additionally, it is difficult to achieve the multi-domain structure of the LC cell. To solve the problems, photo alignment which has non-contact type has been developed [7–12]. This can provide the excellent order parameter for high quality image of the LCDs.

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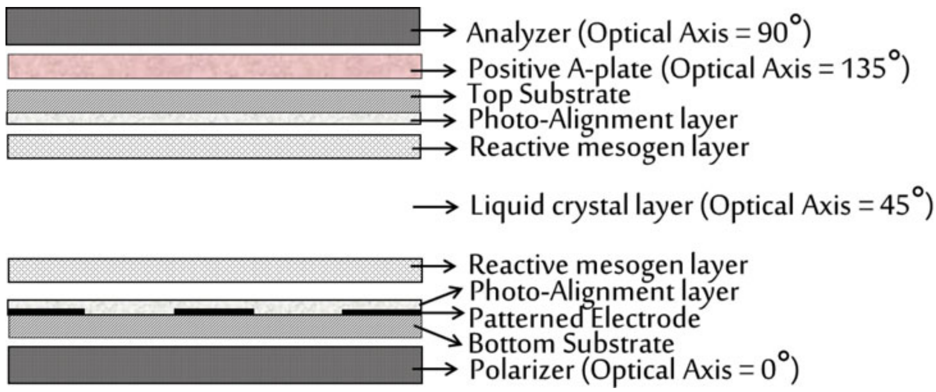

Figure 1. The optical structure of the proposed photo-aligned IPS LC cell for high speed response time.

However, the photo-alignment method has fundamentally insufficient alignment stability, weak surface anchoring energy and unstable pretilt angles because it is generated by illumination of the polarized UV light so that it causes slow response times in LC modes. Recently, LCDs are being required for application to the dynamic moving pictures that need fast response LCDs to minimize the crosstalk as well as the high image quality. Therefore, development of high speed LCDs is also very important.

In our previous study, we reported the retardation free (RF) IPS LC cell with low cell gap for high speed response time by using a retardation film [13]. This cell is not affected by the retardation of the LC cell if it has more than quarter wave retardation. Therefore, the cell gap which is cell parameter for improving the response time can be reduced without any changes in the LC materials so that we can effectively improve the response time. Furthermore, method which can enhance the surface anchoring energy of the photo-alignment layer was proposed by *kim*'s group [10, 14]. They introduced the photo-alignement layer coated with UV curable reactive mesogen (RM) and mixed with RM for enhancing the stability of PA layers.

In this paper, we proposed a high speed IPS LC mode which can provide the free of retardation properties on the photo-alignment layer. We stacked the RMs which can modify the anchoring condition on the alignment layer and applied the free of retardation effect by attaching the positive *A*-plate. In experiment, we measured the surface anchoring energy of a cell with/without RM coating so that the strong anchoring energy can be achieved. We finally demonstrate the response time of the proposed photo-aligned RF IPS LC cell by comparing the conventional IPS LC cell that has photo-alignment layer with/without RM coating.

2. Enhancement of the Optical Response and Image Quality in the Photo-aligned RF IPS Cell

Figure 1 shows the optical configuration of the photo-aligned RF IPS cell for high image quality and fast response time. In general, the photo-alignment method can increase the order parameter of LCs in the LC cell so that it can provide the high image quality in the LCDs. However, the photo-alignment layer causes the slow response time because of the weak anchoring energy and unstable pretilt angles. In this paper, we used the photo-alignment layer covered with UV-curable RMs which can modify the surface conditions, such as polymer chain distribution and molecular interactions for enhancing its surface anchoring energy as shown in Fig. 1. To achieve more high speed response time of the proposed cell, the retardation free configuration that is sequentially stacked by a positive *A*-plate and LC layer between two crossed polarizers is additionally applied. As mentioned in the previous paper [13], the response time can be improved by controlling the parameters of the LC cells. Especially, reducing the cell gap related to the falling time of the LC cell is one of the representative methods for improving the response time. Fundamentally, the response time of an IPS LC cell is defined by summation of the rising time and falling time under applied voltage state. These variables can be calculated as follows [15]:

$$t_{on} = \frac{\gamma d^2}{\varepsilon_0 \Delta\varepsilon \left[\left(E_{input\_eff} \times l \right)^2 - (E_{th\_eff} \times l)^2 \right]}, \; t_{off} = \frac{\gamma d^2}{K_{22}\pi^2} \tag{1}$$

Where, t_{on} and t_{off} are rising and falling times of the IPS LC cell. ε_0, $\Delta\varepsilon$, γ, and K_{22} represent the permittivity in free space, dielectric anisotropy, viscosity and twist elastic constant of the LC material, respectively. The d is the cell gap of the LC layer and the l represents the distance between the electrodes. The E_{input_eff} and the E_{th_eff} represent the effective input electric field and the effective threshold electric field, respectively. In the bright state of an IPS cell, the LC layer should maintain the half-wave retardation. Therefore, the refractive anisotropy (Δn) of the LC materials should be high enough to keep the small cell gap d. In this proposed IPS cell, we applied the positive *A*-plate with quater-wave retardation for maintaining the effective retardation in the bright state as shwon in Fig. 1. The *A*-plate in a LC cell should have exactly same retardation as LC layer, and its optical axis is exactly crossed to the optcial axis of the LC layer. In dark state, polarization fo the light passing through the LC layer is changed to the other polarization state because of the optical axis of 45° in the LC layer. However, the polarization state of the light will return to the polarization axis of the input polarizer by passing through the *A*-plate because the *A*-plate has the same retardation and the crossed optical axis as the LC layer. This can make the excellent dark state. The bright state of the proposed cell can be obtained by rotating the optical axis of the LC layer under applied voltage, so that the summation of the effective Δn of the LC layer and the *A*-plate will be half-wave retardation. Therefore, the Δnd of LC layer is enough as quater-wave in the proposed LC cell, and thus we reduce the cell gap d of the LC layer without changing the LC materials. Consequently, low cell property can induce a fast response time of an IPS LC cell compared with the conventional IPS LC cell.

3. Experiments and Discussions

Figure 2 shows the schematic diagrams of the RM coating system in the proposed IPS LC cell. As shown in Fig. 2(a), the photo-alignment layer (Lixon, PIA-PA77-04X) was spin-coated on two prepared substrates to align the cell layers. Next, it was pre-baked at 100°C for 10 min, followed by curing for complete imidization at 230 °C for 2 hours. The initial spin-coated photo-alignment layer on the substrate has arbitrary alignment before UV exposer. To establish the alignment direction in Fig. 2(b), polymer chains of the alignment layer is broken by using the photo-dissociation alignment method. In this process, the intensity ~12 mW/cm^2 of 365 nm UV light is exposed for 40min. On the aligned photo-alignment layer, RM mixture of a RM (Merck, RM257) and photoinitiator (BASF, Irgacure 184) with

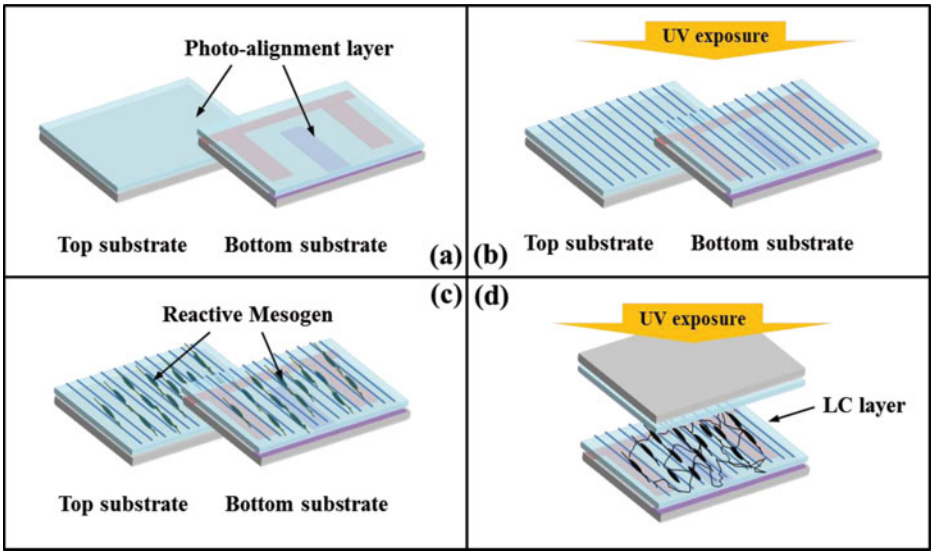

Figure 2. The schematic diagram of the fabrication process of the proposed photo-aligned IPS cell: (a) the spin-coating of the photo-alignment layer, (b) the exposed photo alignment for the LC arrangement, (c) the spin-coating of the reactive mesogen (RM) layer on the photo-alignment layer, and (d) the curing of the RM layer for strong polymeric chain.

a ratio of 2:98 wt% are spin-coated on the alignment layer and then, we baked it at 100 °C for 2 min to evaporate the solvent. Because RMs are liquid crystalline monomers before UV exposure, the spin-coated RM molecules become aligned on the photo-alignment layer, as shown in Fig. 2(c) so that the RM is directionally polymerized along the UV alignment direction. Then, we assembled the prepared two substrates and maintained the cell thickness 3.2 μm by using the ball spacer. Finally, we injected a nematic LC (Merck, ML-0249, $\Delta n = 0.0993$, $n_e = 1.58101$, $n_o = 1.48167$, and $\Delta\varepsilon = 8.4$) into the empty cell, and then we exposed the cell to the UV light of ~12 mW/cm^2 for 2.5 min to increase the anchoring energy from the polymerization as shown in Fig. 2(d).

To improve of the optical response time of the photo-alignment IPS cell, we measured the azimuthal anchoring energy of the fabricated sample that has a 3 μm electrode width and 15 μm interval between the electrodes, with and without RM coating by using the torque balance method [16]. For the measurement of the sample, the initial twist angle is set to 30° and the acutual twist angle (φ_t) was obtained from the angle with the maximum transmittance if the analyzer was rotated to 0.1°. Figure 3 shows the measured azimuthal anchoring energy for each LC alignment method as a function of the actual twist angle. In the LC layer with 24 pitch between 3.2 μm cell thickness, the LC directors on the rubbed alignment layer are averagely twisted to 33.5° so that the high anchoring energy could be shown in Fig. 3. In case of the conventional photo-alignment layer without RM coating, actual twist angle φ_t has 41° and it means the weak azimuth anchoring energy when compared with the rubbed alignment layer. However, polymerized chain of stacked RM layer on the photo-alignment layer combines with LC directors and thus, it can increase the surface anchoring energy of the LC cell. As a result, we can confirm that the measured anchoring energy of the photo-alignment layer with RM coating has values between the rubbed alignment and the photo-alignment layer without RM coating in Fig. 3, this could

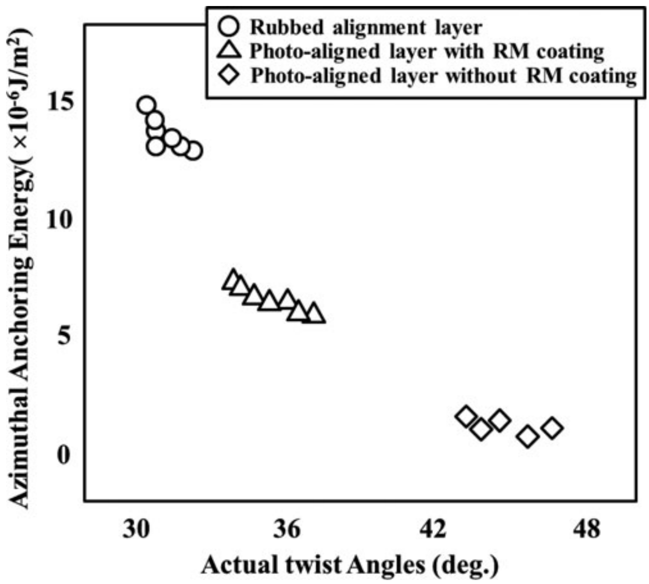

Figure 3. The measured surface anchoring energy of the rubbed alignment layer and the phto-alignment layer with/without RM coating as a function of the actual twist angle φ_t.

be increased to 2 times stronger than that of the conventional photo-alignment IPS cell without RM coating.

To further improve the response time of a photo-aligned IPS LC cell, we additionally reduced the cell gap to 2 μm and attached the positive *A*-plate which has the same effective retardation as the LC layer in the photo-alignment IPS LC cell with RM coating. Figure 4

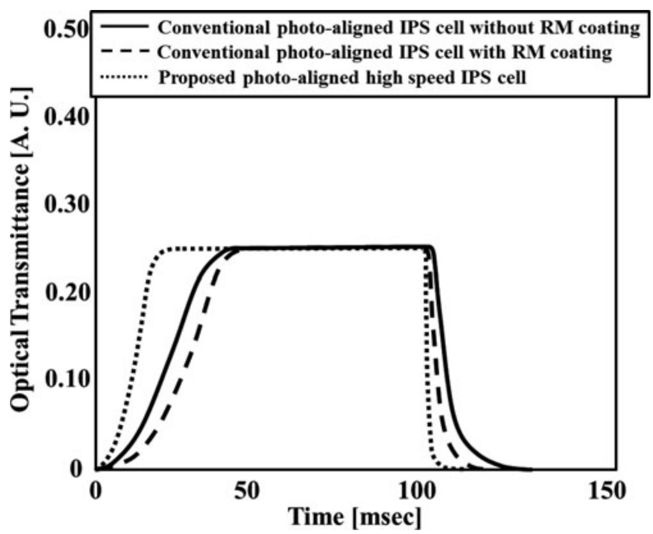

Figure 4. The comparison of the measured optical response time of the proposed photo-aligned high speed IPS cell and the conventional photo-aligned IPS cell with/without RM coating layer.

shows the comparison of the measured optical response time of the proposed photo-aligned high speed IPS cell and the conventional photo-aligned IPS cell with/without RM coating layer. As experimental results, the response time of the IPS cell without RM coating is 58.17 ms which is defined as the rising time of 30 ms and the falling time of 28.17 ms, respectively under an applied 8 volts. In Fig. 4, we can see that the response time of the IPS cell with RM coating was reduced over 22% compared to that of an IPS cell without RM coating, especially, the falling time was significantly reduced because of the strong polymer interaction between the UV curable RMs. In case of the proposed high speed IPS cell, the measured rising and falling time are respectively 14 ms and 8 ms under applied 12.5 volts, so that it leads to improve the response time over 56.86% compared to the IPS cell coated with RMs because the cell gap which is the most important parameter for reducing the response time could be reduced without any degradation of the optical transmittance in bright state. Therefore, we could achieve a very fast speed response time in a photo-aligned IPS LC cell by two methods which consists of the coating of RMs on the photo-sensitive alignment layers and low cell gap properties, so that it may be very useful in high resolution and fast response time LCD applications.

4. Summary

In conclusion, we proposed the fast response time IPS LC cell by using the photo-alignment method. To provide the high speed response time in the proposed LC cell, the photo-alignment layer was coated with the UV curable RMs which can modify the surface anchoring energy, so that we could get the strong anchoring energy and fast falling time in the cell. Furthermore, we applied the low cell gap properties in an IPS LC cell by using an *A*-plate with same effective retardation as the LC layer. From the experiments, we confirmed that the measured response time of the proposed IPS LC cell could be improved over 56.86% and 62.18% compared with a conventional photo-aligned IPS cell with/without RM coating layer without any degradation of the transmittance of the bright state because of the low cell gap. We believe that a proposed configuration can be appropriate to the requirements of the current display applications such as the fast response time and the high resolution image.

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References

[1] Han, K.-Y. & Uchida, T. (1995). *Journal of Soc. Inf. Display*, *3*, 15.
[2] Janning, J. L. (1972). *Appl. Appl. Phys. Lett.*, *21*, 173.
[3] Schadt, M., Schmitt, K., Kozinkov, V., & Chigrinov, V. (1992). *Jpn. J. Appl. Phys.*, *31*, 2155.
[4] West, J. L., Su, L., Artyushkova, K., Farrar, J., Fulghum, J. E., & Reznikov, Y., (2012). *SID Dig. Tech. Papers*, *33*, 1102.
[5] Kim, Y. B., Olin, H., Park, S. Y., Choi, J. W., Komitov, L., Matuszczyk, M., & Lagerwall, S. T. (1995). *Appl. Phys. Lett.*, *66*, 2218.
[6] Zhu, Y.-M., Wang, L., Lu, Z.-H., Wei, Y., Chen, X. X., & Tang, J. H. (1994). *Appl. Phys. Lett.*, *65*, 49.
[7] Galabova, H. G., Allender, D. W., & Chen, J. (1997). *Phys. Rev. E*, *55*, 1627.

[8] Kimura, M., Nakata, S., Makita, Y., Matsuki, Y., Kumano, A., Takeuchi, Y., & Yokoyama, H. (2001). *Jpn. J. Appl. Phys.*, *40*, L352.
[9] Nie, X., Lu, R., Xianyu, H., Wu, T. X., & Wu, S.-T. (2007). *J. Appl. Phys.*, *101*, 103110.
[10] Lee, Y.-J., Baek, J.-H., Kim, Y., Heo, J. U., Yu, C.-J., & Kim, J.-H. (2013). *J. Phys. D: Appl. Phys.*, *46*, 145305.
[11] Chigrinov, V. G., Kozenkov, V. M., & Kwok, H.-S. (2008). *Photoalignment of Liquid Crystalline Materials: Physics and Appications* (Wiley, New York, USA).
[12] Yaroshchuk, O., kyrychenko, V., Tao, D., Chigrinov, V., Kwok, H. S., Hasebe, H., & Takatsu, H. (2009). *Appl. Phys. Lett.*, *95*, 021902.
[13] Kang, W. S., Moon, J.-W., Lee, G.-D., Lee, S. H., Lee, J.-H., Kim, B.-K., & Choi, H. C. (2011). *J. Opt. Soc. Korea*, *15*, 161.
[14] Moon, Y.-K., Lee, Y.-J., Jo, S. I., Kim, Y., Heo, J. U., Baek, J.-H., Kang, S.-G., Yu, C.-J., & Kim, J.-H. (2013). *J. Appl. Phys.*, *113*, 234504.
[15] Yeh, P. & Gu, C. (1999). *Optics of Liquid Crystal Displays* (Wiley, New York, USA).
[16] Kawamura, M., Goto, Y., & Sato, S. (2004). *Jpn. J. Appl. Phys.*, *43*, 6239.