Fast vertical alignment mode with continuous multi-domains for a liquid crystal display

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Abstract: We proposed a fast liquid crystal display (LCD) in a vertical alignment (VA) mode with continuous multi-domains for wide-viewing characteristics. The fast VA LCD was fabricated by the mixed vertical alignment layer with UV curable reactive mesogen (RM) polymer memorizing the switching directions of the LC molecules. The wide-viewing and fast response characteristics were obtained by axially symmetric switching directions and the memorization of them without any specific electrode patterns or surface structures.

OCIS codes: (120.2040) Displays; (230.3720) Liquid-crystal devices.

References and links

1. K.-Y. Han, and T. Uchida, "A study of the relation between surface alignment of polymers and liquid-crystal pretilt angle," J. Soc. Inf. Disp. **3**(1), 15–21 (1995).
2. J. L. Janning, "Thin film surface orientation for liquid crystals," Appl. Phys. Lett. **21**(4), 173–175 (1972).
3. M. Schadt, K. Schmitt, V. Kozinkov, and V. Chigrinov, "Surface-induced parallel alignment of liquid crystals by linearly polymerized photopolymers," Jpn. J. Appl. Phys. **31**(Part 1, No. 7), 2155–2164 (1992).
4. L. Komitov, "Nano-engineering of the anchoring of liquid crystals on solid surfaces," Thin Solid Films **516**(9), 2639–2644 (2008).
5. M. Oh-e, and K. Kondo, "Electro-optical characteristics and switching behavior of the in-plane switching mode," Appl. Phys. Lett. **67**(26), 3895–3897 (1995).
6. M. Oh-e, M. Yoneya, M. Ohta, and K. Kondo, "Dependence of viewing angle characteristics on pretilt angle in the in-plane switching mode," Liq. Cryst. **22**(4), 391–400 (1997).
7. 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. **73**(20), 2881–2883 (1998).
8. I. H. Yu, I. S. Song, J. Y. Lee, and S. H. Lee, "Intensifying the density of a horizontal electric field to improve light efficiency in a fringe-field switching liquid crystal display," J. Phys. D **39**(11), 2367–2372 (2006).
9. P. J. Bos, L. R. Koehler, and beran, "The pi-cell: a new, fast liquid-crystal optical switching device," Mol. Cryst. Liq. Cryst. (Phila. Pa.) **113**(1), 329–339 (1984).
10. Y. Yamaguchi, T. Miyashita, and T. Uchida, "Wide-viewing-angle display mode for the active-matrix LCD using bend-alignment liquid-crystal cell," Digest of Technical Papers of 1993 Society for Information Display International Symposium, 277–280 (1993).
11. S. Yamauchi, M. Aizawa, J. F. Clerc, T. Uchida, and J. Duchen, "Homeotropic-alignment full-color LCD," Digest of Technical Papers of 1989 Society for Information Display International Symposium, 378–381 (1989).
12. S. Ohmuro, S. Kataoka, T. Sasaki, and Y. Koike, "Development of super-high-image-quality vertical-alignment mode LCD," Digest of Technical Papers of 1997 Society for Information Display International Symposium, 845–848 (1997).
13. 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," Digest of Technical Papers of 1998 Society for Information Display International Symposium, 1077–1080 (1998).
14. K. Sueoka, H. Nakamura, and Y. Taira, "Improving the moving-image quality of TFT-LCDs," Digest of Technical Papers of 1997 Society for Information Display International Symposium, 203–206 (1997).
15. K. H. Kim, K. Lee, S. B. Park, J. K. Song, S. N. Kim, and J. H. Souk, "Domain divided vertical alignment mode with optimized fringe field effect," Proceeding of The 18th International Display Research Conference Asia Display, 383–386 (1998).

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16. N. Yamada, S. Kohzaki, F. Funada, and K. Awane, "Axially symmetric aligned microcell (ASM) mode: electrooptical characteristics of new display mode with excellent wide viewing angle," Digest of Technical Papers of 1995 Society for Information Display International Symposium, 575–578 (1995).
17. S. H. Lee, S. H. Park, M.-H. Lee, S. T. Oh, and G.-D. Lee, "Homeotropically aligned nematic liquid crystal device locked by a polymer wall with wide viewing angle," Appl. Phys. Lett. **86**(3), 031108 (2005).
18. S.-F. F. Chen, Y.-Y. Chang, L. C. Chow, H.-M. P. Chen, and H.-P. D. Shieh, "Digest of Technical Papers of 2009 Society for Information Display International Symposium, 1592-1594 (2009).
19. Y.-J. Lee, Y.-K. Kim, S. I. Jo, J. S. Gwag, C.-H. Yu, and J.-H. Kim, "Surface-controlled patterned vertical alignment mode with reactive mesogen," Opt. Express **17**(12), 10298–10303 (2009).
20. P. G. de Gennes, J. Prost, The Physics of Liquid Crystals, (Oxford Univ. Press, New York, 1993).

1. Introduction

The liquid crystal displays (LCDs) have been extensively studied and used for a wide range of display applications such as mobile phones, monitors, and televisions because of their high image qualities with low power consumption. In general, the uniform alignment of LC molecules is essential to govern the display performances. To obtain the uniform alignment, various approaches have been reported including rubbing method of polymer films [1], evaporation of silicon monoxide (SiOx) [2], UV exposure of photopolymers [3], and surface modification with applied voltage during photo-alignment process [4]. However, a narrow viewing characteristic is inevitably involved in a traditional mono-domain LCD. To improve the viewing angle property, various LCD modes with multi-domains such as in-plane switching (IPS) [5,6], fringe-field switching (FFS) [7,8], optically-compensated bend (OCB) [9,10], multi-domain vertical alignment (MVA) [11–13], patterned vertical alignment (PVA) [14,15] have been developed. Among them, the MVA and PVA modes do not require the rubbing process but need to pattern the top and bottom electrodes to control the switching directors of the LC molecules. In such cases, however, another manufacturing process is needed for patterning the electrodes. In addition, the intrinsically axial-symmetric modes such as axially symmetric aligned microcell (ASM) [16] mode and locked-super homeotropic (LSH) [17] mode showed very slow response time because of the stabilization of the defect structures including point singularities and disclination lines under an applied voltage.

In this work, we proposed a fast vertical alignment (VA) mode with continuous multi-domains for wide-viewing characteristics without any specific electrode patterns or surface structures. The fast VA mode was fabricated by the mixed vertical alignment layer with reactive mesogen (RM) which was polymerized by UV exposure under an applied voltage. In this VA mode, the polymerized RM memorized the switching directions of the LC molecules with axial symmetry and thus improved the response time due to the removal of the reorientation process inevitably involved in the conventional VA mode without rubbing, electrode patterning, or surface modifying processes. As a result, fast response and wide-viewing characteristics were achieved in our surface-controlled (SC) VA mode using the simple fabricating processes.

2. Experiments

Figure 1 shows the schematic diagram of fabrication process. The RM monomer which is used for inner retardation film and modification of surface [18] was mixed in vertical alignment material (AL60101, JSR, Japan) with less than 5 wt%. The alignment layer was obtained by spin coating on the ITO substrate having no particular electrode pattern for generating oblique electric field and prebaked at 80 °C for 10 min followed by curing at 180 °C for 1 hour. The cell thickness of the assembled substrates is maintained by the use of 3 μm glass spacers. The LC (MLC-6610, $\Delta\varepsilon = -3.1$ and $\Delta n = 0.0996$, Merck) are injected into the assembled cell by capillary action in the isotropic phase. At an initial state, the LC molecules were aligned vertically on the substrate and RM monomers were distributed uniformly within the alignment layer at the monomer state, as shown in Fig. 1(a). When applied voltage larger than threshold voltage (V_{th}), the LC molecules fell down randomly, and the RM monomers aligned along the LC molecules [Fig. 1(b)]. The RM monomers are easily dissolved in the LCs and movable due to the liquid crystalline property of RM [19]. After a few times later until the LC directors, defects, and disclination lines are stabilized, the cell was exposed to the

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UV light of 4 mW/cm^2 for 30 min with applied 4 V, and then the RM monomers were polymerized in the alignment layer [Fig. 1(d)]. Finally, the unrubbed alignment layers kept in the memory of the LC director at this structure even after removing the electric field [Fig. 1(c)].

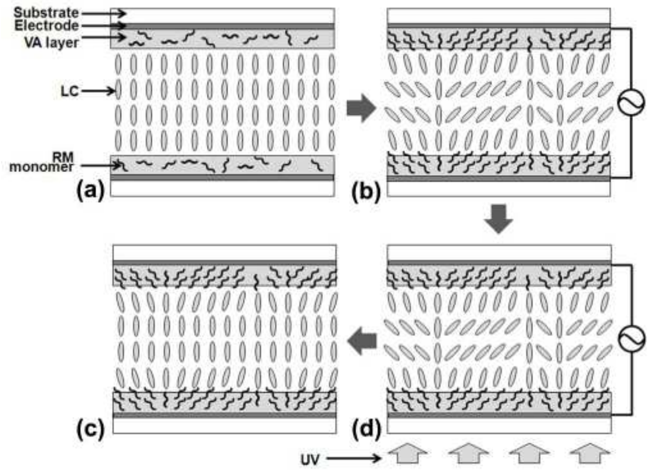

Fig. 1. The schematic diagram of our SC VA mode and the fabrication processes.

3. Results and discussion

Figure 2 shows the microscopic textures under crossed polarizers for conventional VA mode and proposed SC VA mode without rubbing process in both cases. The LC molecules aligned vertically on the alignment layer surface without electric field at their initial state. In the presence of the electric field, the LC molecules fall down to the surface with random azimuthal direction due to unrubbed alignment surface, which generate the 4-brush ($s = \pm1$) defects [20]. After that, the LC molecules are reoriented to minimize the free energy with changing the position of core of disclination lines and point defects [see in Fig. 2(a)]. When switching the electric field (i.e. on and off the electric field), the LC directors changed every time, so we always get the different textures [compare with Figs. 2(a), 2(b) and 2(c)]. In the SC VA cell, the LC directors are also aligned randomly in the presence of electric filed and then reoriented. But, after UV exposure with applied voltage, RM polymers in the alignment layer memorize the LC directors because the polymers elongated with the LC directors during UV exposure with electric field. Therefore, the LC directors when applied the voltage fall down to the surface with the fixed azimuthal direction along the RM polymers without any reorientation processes for minimizing the free energy. As a result, we can always obtain the same microscopic textures at the same position [see Figs. 2(e), 2(f) and 2(g)]. Though many 4-brush defects decrease the transmittance, we can overcome this problem using two $\lambda/4$ retardation films that each films located between polarizer and glass substrate of top and bottom, respectively, by 45° with respect to the optic axis of polarizer as conventional LCD does. Because the linearly polarized light through after polarizer is changed to circularly polarized light due to $\lambda/4$ retardation film, the area in which the direction of LC molecules and polarizers are parallel or perpendicular each other is not dark state but bright state, as a result, we could increase the transmittance [see Fig. 2(d) and 2(h)].

In conventional VA mode without rubbing process, a response time, particularly rising time, is very slow because the LC molecules aligned with reorientation process in the presence of electric field for minimizing the free energy, as mentioned above. Figure 3(a) shows the time-resolved microscopic textures of conventional VA mode under crossed polarizers. As shown in textures, since the azimuthal tilting down directions of the LC molecules is not defined, it takes more than 10 sec to reach the stable state through the

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reorientation process. On the contrary, our SC VA mode has very fast response characteristics because the memorized azimuthal tilting-down direction by the RM polymer guide to the stable alignment state of the LC molecules without reorientation process. So, it takes less than 3 msec with applied 8 V [see Fig. 3(b)].

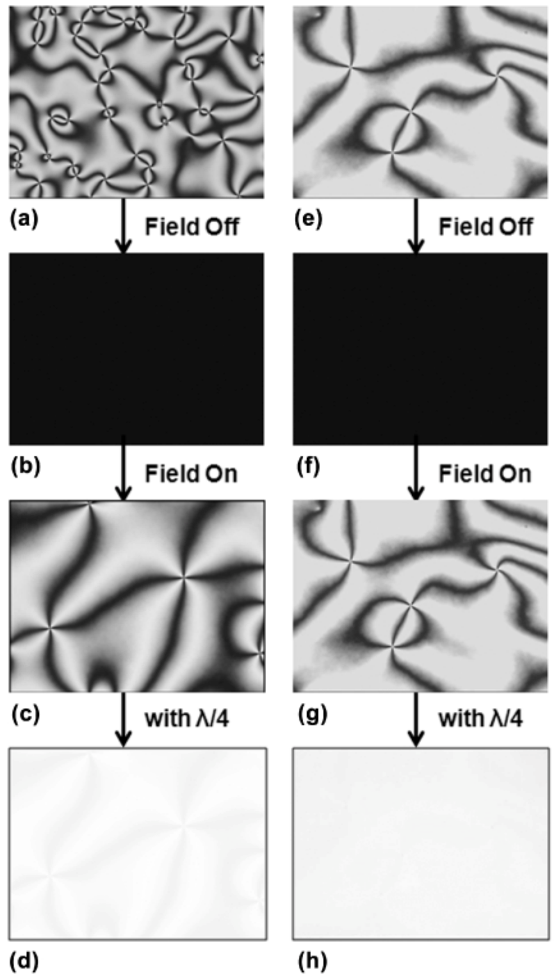

Fig. 2. Microscopic textures under crossed polarizers for (a)-(d) the conventional VA mode and (e)-(h) the SC VA mode with the electric field switching.

Figure 4 shows the entire response time characteristics of our SC VA cell as a function of applied voltage. The rising and falling times are 2.8 msec and 7.6 msec, respectively, at applied 8 V which is fast enough for moving pictures. It is reason why the RM polymers which are kept in memory of the azimuthal direction make the pretilt angle on the alignment layer. With increasing the pretilt angle using high applied voltage during curing RM monomers and high concentration ratio of RM polymers in the alignment layer, faster response time can be realized, but that make possible the light leakage in the dark state resulting in a lower contrast ratio because the pretilt angle generates effective retardation under crossed polarizer. Therefore, the optimized conditions were required for reach high display performance. In our experience, we applied 4 V during UV curing process for fast response time and high contrast ratio.

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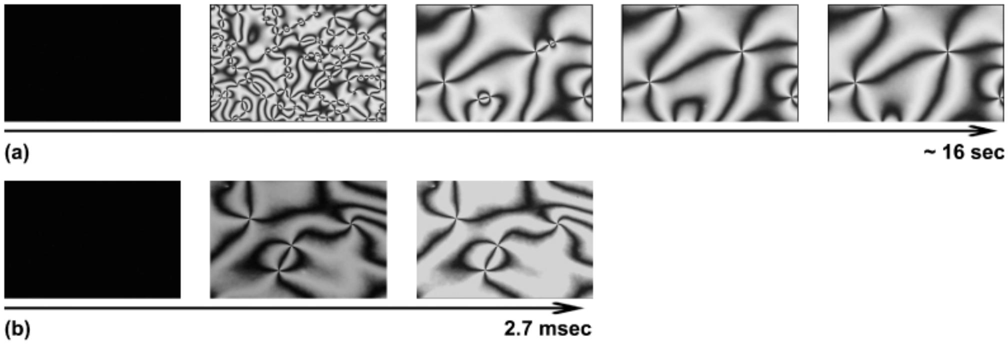

Fig. 3. The time-resolved microscopic textures under crossed polarizers with 10 V for (a) the conventional VA mode without rubbing process and (b) the SC VA mode.

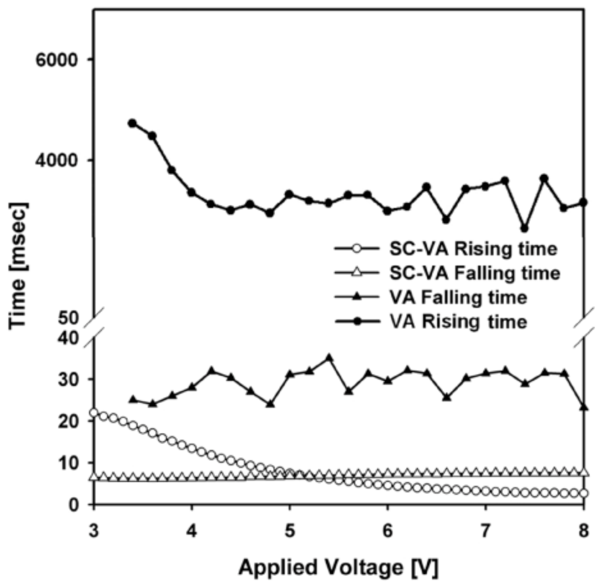

Fig. 4. Response time characteristics of the conventional VA mode and the SC VA mode.

Figure 5 shows the experimental results of viewing angle characteristics between above two VA modes. For the conventional VA mode, the LC directors are well aligned unidirectionally along the rubbing directions, so it has uniform textures and high transmittance. But viewing angle characteristics are not uniform at various polar and azimuthal angles because the effective retardation values are different for different viewing direction [see Fig. 5(a)]. In our SC-VA mode, the LC directors are axially symmetric due to continuous domain, as a result, we can get the uniform transmittance characteristics for all azimutal angles at each polar angle in white state [see Fig. 5(b)].

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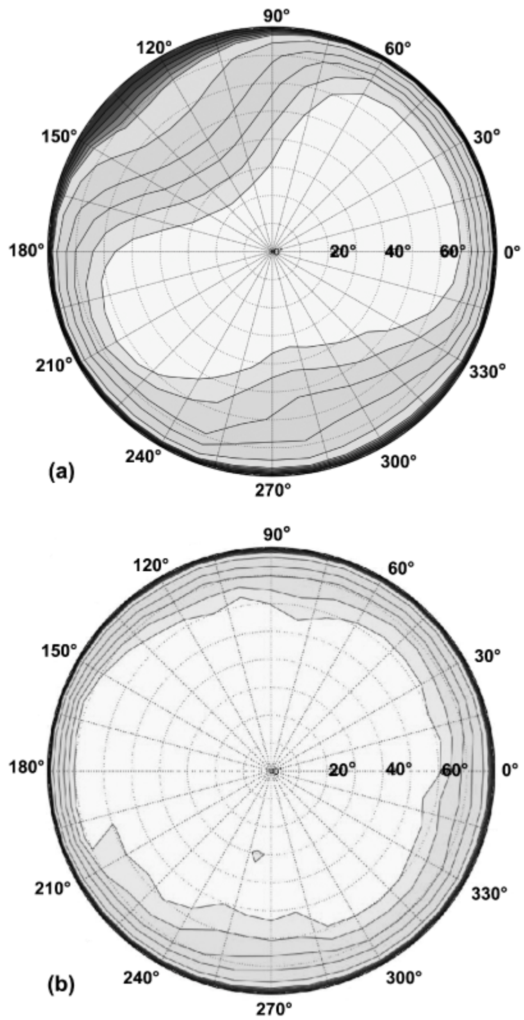

Fig. 5. Comparison of brightness viewing characteristics between (a) the conventional VA mode with rubbing and (b) the SC VA mode.

4. Conclusion

In summary, we proposed the fast SC VA mode with continuous multi-domains using RM polymers within alignment without conventional alignment process such as rubbing. In the presence of electric field, the LC molecules fell directly down to the substrate along the memorized direction by RM polymers in the alignment surface. As a result, the fast response and wide-viewing characteristics were obtained in the simple fabricating processes. The SC VA mode is expected to become a viable technology to produce the large-sized LCDs with the excellent display performances.

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