Surface-controlled patterned vertical alignment mode with reactive mesogen

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Abstract: We proposed a patterned vertical alignment (PVA) mode controlled by a modified surface with ultraviolet (UV) curable reactive mesogen (RM) mixed with vertical alignment material for a liquid crystal display (LCD) with fast response time. In the surface-controlled PVA (SC-PVA) mode, the RM monomers in the alignment layer are polymerized along the LC directors by UV exposure under an applied voltage. The polymerized RMs produce a pretilt against the substrate normal depending on the applied field direction in the patterned electrode configuration. In such SC-PVA mode, fast response time was achieved at whole grey levels with the predetermined rotational preference of the LC directors governed by the pretilt direction.

OCIS codes: (230.3720) Liquid-crystal devices.

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1. Introduction

The demand for the large-sized flat panel displays has been increased by the expansion of the digital television (TV) market. Especially, thin-film-transistor liquid crystal displays (TFT-LCDs) for the TV applications have been extensively studied and widely used because of the advantages of high resolution, light weight, thin thickness, and low power consumption. The variety of LC modes such as in-plane switching (IPS), fringe-field switching (FFS), multidomain vertical alignment (MVA), and patterned vertical alignment (PVA) modes has been developed to achieve the high performance LCDs [1-6]. In particular, the PVA mode, where the LCs are vertically aligned in alternatively patterned pixel and common electrodes, is one of the most promising LC modes for the large-sized display applications due to fast decay time, rubbing-free fabrication process, high contrast ratio at a normal direction, and wide viewing characteristics in the multidomain structure. However, the LC modes using the multidomain structures for wide viewing angle such as the PVA and MVA modes reveal a slow rising time (that is, field-driven response time) and low transmittance owing to the nonuniform distribution of the applied electric field from the patterned electrodes.

In a typical PVA mode, when no electric field is applied the LC directors are vertically aligned in the alternatively patterned pixel and common electrodes and a dark state is obtained under crossed polarizers. In the presence of the electric field, the LC directors are tilted out of the substrate normal toward a direction perpendicular to the fringe field generated by the alternatively patterned electrodes because of their negative dielectric anisotropy. At first, the director tilt starts near the edges of the patterned electrodes and then propagates into the center of them. In this situation, the defects were initially formed near the center of two overlapping electrodes (pixel and common electrodes) because no fringe field was generated at the center of them and no preference of the tilting direction was produced. After the director tilt propagated into the center of the overlapping electrodes, the LC directors were unidirectionally stabilized within the overlapping electrodes without any defects. These processes of the defect formation and the director stabilization critically give rise to the increase of the response (rising) time. In order to improve the slow response time in the PVA mode, the overdriving technologies, so called dynamic capacitance compensation (DCC I [7,8] and DCC II [9]), were proposed. In these cases, however, the driving schemes were complicated and additional processes were required, which increase the manufacturing costs.

Recently, Kim's *et al.* [10] proposed a polymer-stabilized PVA (PS-PVA) mode using the mixture of LCs with reactive mesogen (RM) [11] to generate the pretilt angle and improve the response time. In the PS-PVA mode, the pretilt directions were determined by polymerization of RM monomers through the illumination of ultraviolet (UV) light in the presence of an electric field. The rotational preference of the LC molecules governed by the pretilt direction reduced a threshold voltage and the response time. However, it is possible to generate severe image degradation such as image sticking since the remaining uncured monomers in the LCs could be acted as impurities.

In this paper, we propose a surface-controlled PVA (SC-PVA) mode fabricated with a mixed vertical alignment layer with the RM monomers. The pretilt directions are determined by the direction of the fringe field and fixed by UV exposure in the presence of the applied electric field similarly to the PS-PVA mode. As a result, the SC-PVA mode shows dramatic improvement of response time at whole grey levels without any defects of disclinations. Moreover, the RM monomers do not give rise to any severe degradation of the image quality since they are confined in the alignment layer.

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2. The configuration of SC-PVA mode

Figure 1 shows the schematic diagram of a fabrication process of the SC-PVA mode. The mixture of the vertical alignment material AL60101 (JSR, Japan) and RM257 (BASF, Germany) with less than 5 wt% was spin coated on both patterned ITO substrate with a chevron shape. The alignment layer was pre-baked at 80 °C for 10 min followed by curing at 180 °C for 1 hour. The cell thickness was maintained using glass spacers of 3.0 μm and filled with LC material (MLC-6610, $\Delta\varepsilon = -3.1$ and $\Delta n = 0.0996$, Merck). At an initial state, the LC molecules were aligned vertically and the RM mononers were distributed randomly in the alignment layer as shown in Fig. 1(a). When a voltage was applied larger than a certain threshold voltage (V_{th}), the LC molecules fell down perpendicular to the electric field, similarly to a conventional PVA mode, and the RM monomers were aligned along the LC molecules (Fig. 1(b)) [12]. The RM monomers are easily dissolved in the LCs and movable due to the liquid crystalline property of RM. Under the applied electric field, the LC cell was exposed to the UV light, and then the RM monomers were polymerized in the alignment layer (Fig. 1(c)). The polymerized RMs produce the pretilt whose azimuthal direction are determined by the direction of the fringe field and fixed by UV exposure in the presence of the applied voltage. It should be noted that the pretilt angles depend on the curing voltage, exposure time, RM concentration, and so on. The pretilts still remained at whole region after curing the RM monomers completely and removing the curing voltage as shown in Fig. 1(d). Finally, the multi-directional pretilts in the PVA mode with the multidomain structure were obtained in the whole domains with no multi-rubbing process, which remarkably reduced the response time in the proposed SC-PVA mode.

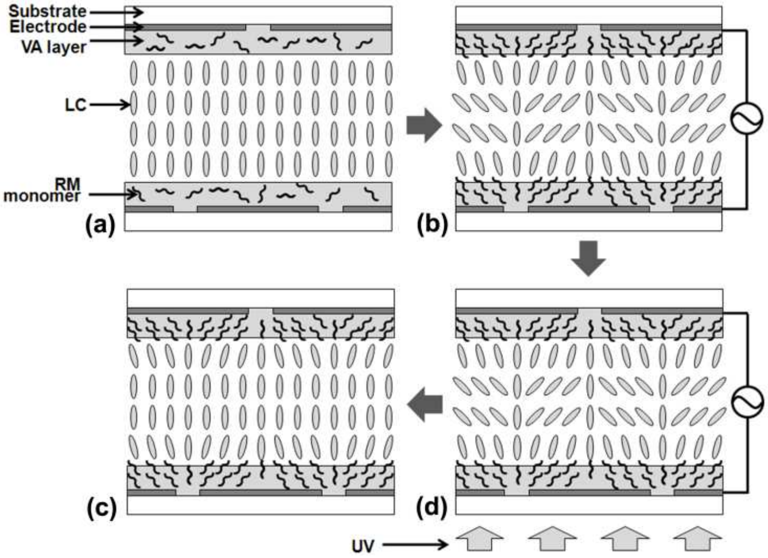

Fig. 1. The schematic diagram of the SC-PVA mode and fabrication processes.

3. Experimental result

The voltage-transmittance (V-T) curves of the SC-PVA cells fabricated with different curing voltages were shown in Fig. 2. As increasing the curing voltages, the V-T curves shifts to left, that is, the threshold voltages decrease, which implies that the pretilt angle is introduced and their amount depends on the applied voltage during UV curing process. The pretilt angles were estimated by the numerical simulations performed with TechWiz LCD (Sanayi System Co., Korea) as shown in Fig. 2(b). In the simulations, the pretilt angles of the SC-PVA modes cured at 3, 4, and 5 V were measured to be 86, 83, and 81°, and the threshold voltages were obtained to be 2.4, 1.9, and 1.7 V, respectively. On the other hand, the threshold voltage of the

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conventional PVA mode is 3.4 V in the same cell conditions. It should be noted that with increasing the applied voltage above a certain voltage during UV curing process, the LC directors gradually fall down and thus the effective retardation is introduced even in the absence of the electric field. As a result, the contrast ratio is reduced because of a light leakage at the dark state.

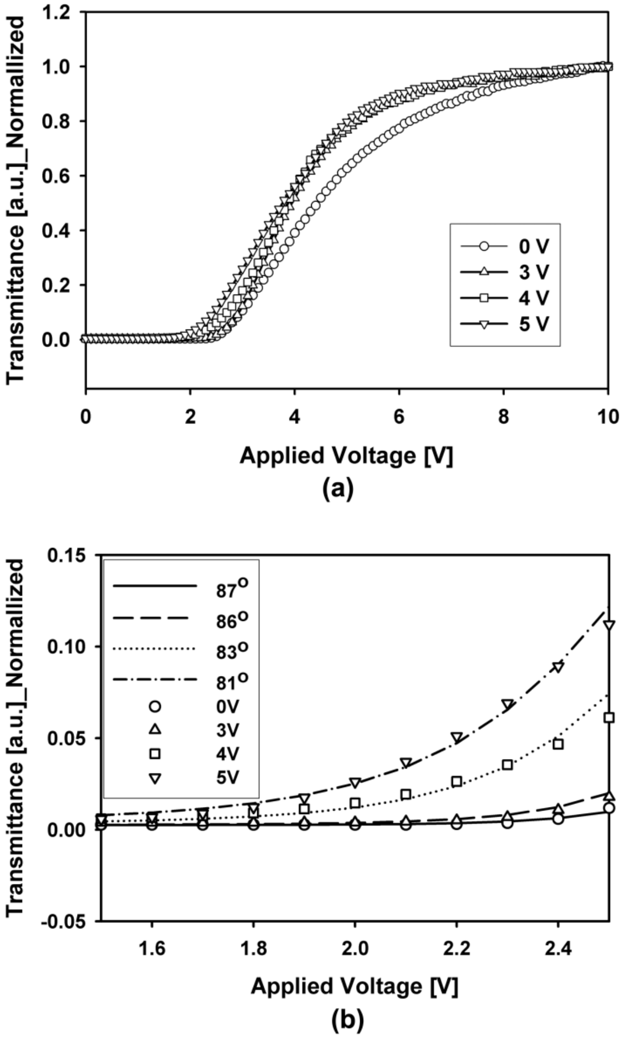

Fig. 2. (a) The measured V-T characteristics of the SC-PVA cell as a function of the applied voltage and (b) the simulated V-T characteristics of the SC-PVA cell near the threshold voltage for various pretilt angles.

Figure 3 shows the time-resolved LC textures of the conventional PVA and the SC-PVA cells to investigate the stability of LC reorientation under an applied voltage. In the conventional PVA cell, the defect patterns were observed within the overlapping regions of the pixel and common electrodes, which give rise to slow response time during the switching as shown in Fig. 3(a). The defects are produced by the uncontrolled tilting direction of LC molecules in the electrode-overlapping regions where the direction of the applied electric field is perpendicular to the substrates without the fringe field. On the contrary, the SC-PVA cell cured at 4 V shows uniform texture during the switching without any point defects and disclination lines as shown in Fig. 3(b) due to the pre-defined pretilt angle by the polymerized RMs. The result clearly indicates that the proposed SC-PVA mode suppresses the formation of defects and improves the rising time. In fact, the rising time to reach stabilized state of conventional PVA mode was 23.2 ms and that of the SC-PVA one was 4.4 ms at 7 V.

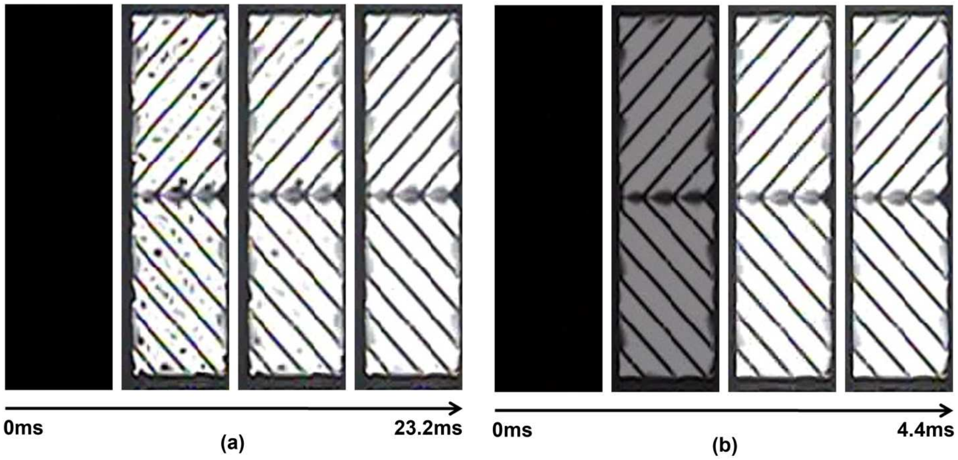

Fig. 3. The time-resolved microscopic textures for (a) the conventional PVA cell and (b) the proposed SC-PVA cell at 7 V.

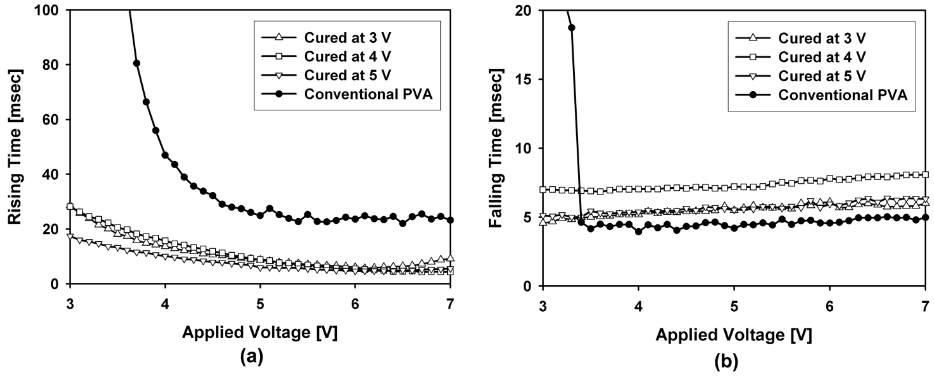

Fig. 4. The electro-optic responses of the conventional PVA cell and the SC-PVA cell as a function of the applied voltage for (a) the rising process and (b) the falling process.

Figure 4 shows the response time characteristics for both the conventional PVA and the SC-PVA cells as a function of the applied voltage. The rising time of the SC-PVA cell was about twice faster than the conventional PVA cell at whole grey levels as shown in Fig. 4(a). The cell cured at 3 V has not enough high pretilt angle to make preference of falling direction. In the electrode-overlapping regions, when a high voltage was applied, the LC molecules fall down randomly due to no fringe field. Then, the LC molecules are reoriented to reduce the deformation energy, which give rise to slow rising time.

In Fig. 4(b), however, the falling time was slightly increased because the elastic deformation energy was decreased due to the pretilt angles. As aforementioned, with increasing the curing voltage, the response time would be faster but the contrast ratio is decreased due to a light leakage by the introduction of the effective retardation at dark state. With increasing the applied voltage, the falling times are slightly goes up because the switching angle returned to the initial state is increased.

4. Conclusion

In summary, we proposed the SC-PVA mode with fast response time by controlling the LC directors on the alignment layer with UV curable RMs. The RM monomers mixed in alignment layer are polymerized along the LC directors by UV exposure under an applied voltage. The polymerized RMs produce the pretilt whose azimuthal direction are determined by the direction of the fringe field and fixed during UV exposure process. As a result, the multi-directional pretilts in the multidomain structure were obtained in the whole domains with no multi-rubbing process, which made possible to realize the fast response time and high display performances.

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