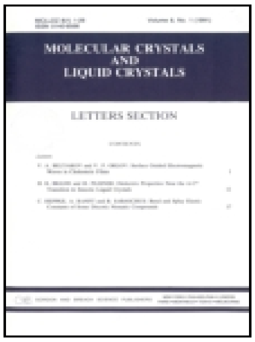

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Fast Response and Wide Viewing Angle Vertical Alignment Mode with X-Shape Electrode

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We proposed the fast response and high transmittance vertical alignment mode by generating the axial symmetry of the liquid crystal (LC) director. To control the LC director, we adopt the x-shaped slit electrode on the only pixel electrode. Using a polymerization of the reactive mesogens (RMs) mixed into the alignment layers, we can memorize the falling direction of LCs and thus the fast switching characteristics can be achieved. Owing to infinite LC domains with the axial symmetry, wide viewing angle characteristics was achieved and high transmittance also was obtained by introducing a quarter wave plate.

Keywords liquid crystal display; wide-viewing angle; reactive mesogen

1. Introduction

Liquid crystal displays (LCDs) have been front leading devices among the various display devices due to its light weight, low driving voltage high resolution, and low fabrication cost. However, the LCDs have some intrinsic problems such as slow response time originated from the rotation of LC molecules and narrow viewing angle after passing through polarizers. To overcome the viewing angle problem, multi-directionally aligned LC modes, have been proposed such as in-plane switching [1], fringe-field switching [2, 3], patterned vertical alignment (PVA) [4], multi-domain vertical alignment [5] and azimuthally continuous domain (ACD) modes [6]. Especially, the ACD mode exhibits the omni-directional alignment of the LC molecules under an applied voltage and thus shows the wide-viewing characteristics. In the ACD mode, however, the electrode-patterning processes in both substrates are inevitably involved. In addition, the response time is relatively slow due to the reconfiguration of the LC molecules under the applied voltage.

Recently, by introducing the reactive mesogen (RM) into the alignment layer, the fast response as well as wide-viewing angle characteristics were obtained in the vertical alignment modes [7, 8]. In this work, we propose a multi-directional vertical alignment mode with wide viewing angle characteristics by patterning the only pixel electrode with x-shape. Also, we introduced the RM into the alignment layer for the fast response time characteristics by memorizing the rotation direction of the LC molecules.

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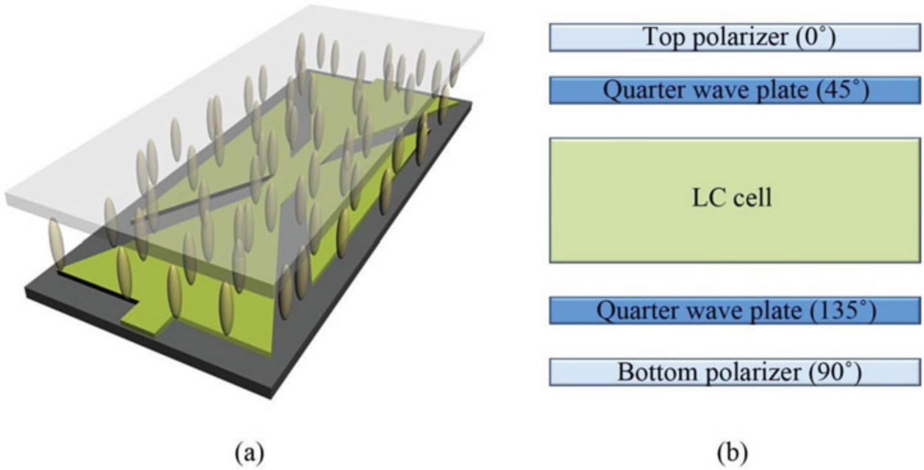

Figure 1. Electrode configurations of the proposed (a) x-shaped electrode and (b) cell structure for the optical compensation.

2. Experimental

Figure 1 (a) shows the proposed cell structure with the x-shaped slit electrode. By using photo-lithography process, the x-shaped indium tin oxide (ITO) electrode was prepared and the slit width of the electrode was 10 μm. The ITO glass substrate was cleaned with mucasol and washed with the di-ionized water. The RM (RM257, E. Merck) with 2 wt.% and photo-initiator (Irgacure 651, CIBA Chem) were mixed to a vertical alignment material (AL1H659, JSR). The mixed alignment materials was stirred with magnetic bar about a day to sufficiently mix. Those mixtures are spin coated on the glass substrate with 1000 rpm for a dispensing step and 3000 rpm for a coating step. The thickness of the alignment layer was about 150 nm. The cell was pre-baked on the hot plate at 100°C to remove the solvent and then fully cured at 180°C to imidize the alignment material.

The cell gap was maintained about 3 μm with glass spacer and nematic LC (MLC-6608, E. Merck) with negative dielectric anisotropic ($\Delta\varepsilon = -3.2$, $\Delta n = 0.083$) was injected to the LC cell by using capillary force around the nematic-to-isotropic transition temperature. Ultraviolet (UV) was exposed in the presence of the voltage with a square waveform at 1 kHz by using an arbitrary waveform generator (DS345, Stanford Research Systems). The intensity of the UV was 10 mW/cm^2 at 365 nm wavelength. To improve transmittance of the multi-directionally aligned LCs, the orthogonal circular polarizers were used by inserting quarter-wave plates (QWPs) as shown in Fig. 1(b). The electro-optical (EO) characteristics measurements were carried out using digitizing oscilloscope (TDS-540, Tektronix) and a light source of a He-Ne laser with the wavelength of 632.8 nm at darkroom circumstance. The viewing angle characteristics were measured by the measurement equipment (EZ-contrast, Edlim).

3. Results and Discussion

Figure 2 shows the microscopic textures of the fabricated sample under orthogonal polarizers. At an initial state, the LC molecules are vertically aligned due to the alignment layer and thus an incident light from the backlight unit is blocked under crossed polarizers as

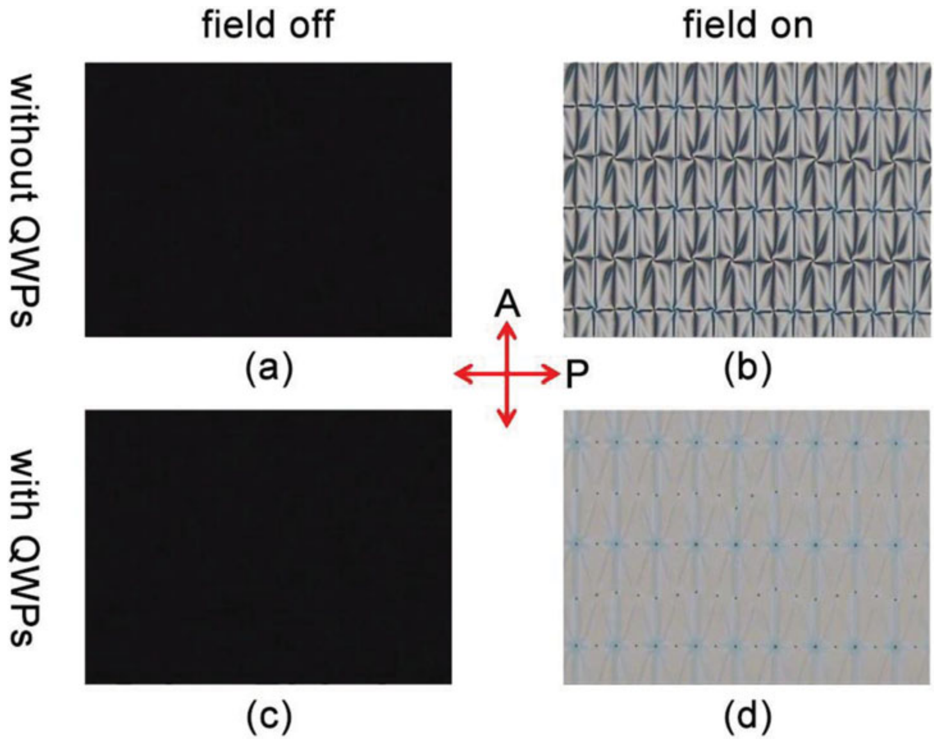

Figure 2. Polarized microscopic textures of the sample (a) without and (b) with QWPs.

shown in Fig. 2(a). On the other hand, when the electric field is applied to the sample, the LCs start to fall down to the substrate and generate the phase retardation. The x-shaped slit electrode generates a fringe field and thus transmittance is varied according to an angle with respect to one of crossed polarizers as shown in Fig. 2(b). In general, the LC molecules near the slit area firstly fall down to the substrate and are rearranged perpendicular to the slit electrode directions. In a low voltage regime, the LC directors propagate from the slit edges to the center of the electrode area. As a result, continuously varying LC directors are obtained and thus the 4-brush defect structures were observed by a polarizing optical microscope as shown in Fig. 2(b).

Under crossed polarizers, however, when the LC directors are parallel to one of the crossed polarizers, no phase retardation was experienced and thus transmittance was degraded. To improve transmittance of the continuously varying LC directors, two QWPs were introduced as shown in Fig. 1(b). Under no applied voltage, two crossed polarizers and two QWPs exhibit orthogonal polarizer configuration and thus dark state is achieved as shown in Fig. 2(c). Under the applied voltage, a linearly polarized light passing through the first polarizer is changed to a circularly polarized light by the first QWP irrespective of the azimuthal direction of the LC molecules. The phase retardation of the LC cell converts the handedness of the circularly polarized light [8]. Finally, the second QWP changes to the orthogonally linear polarization and thus bright state was obtained as shown in Fig. 2(d). As shown in Fig. 3, the EO transmittance of the sample with the QWPs under crossed polarizers was enhanced about 66% comparing the sample without the QWPs.

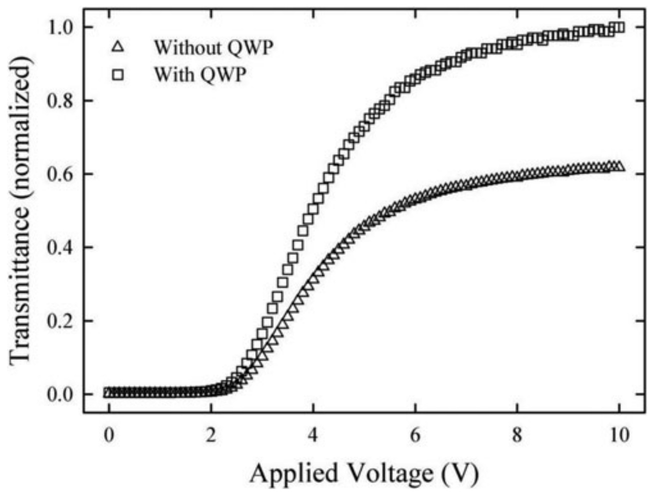

Figure 3. EO transmittances of the sample (a) without and (b) with QWPs.

Figure 4 shows the time-resolved textures of the proposed sample. In the case of the vertical alignment layer without the RM, the LC molecules was varied until reaching stable director configuration under the applied voltage and a reorientation time was quite long about 500 ms as shown in Fig. 4(a). We introduced the RM to the vertical alignment material to remove the reconfiguration process of the LC directors under the applied voltage by memorizing the stable falling directions. To memorize the stable azimuthal directions of

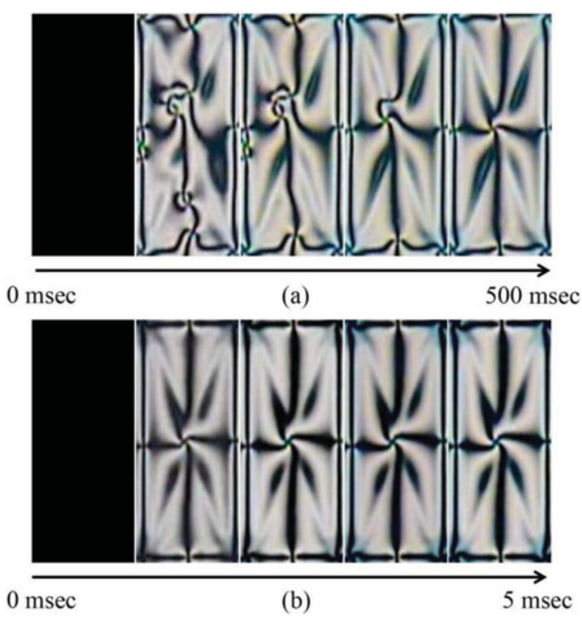

Figure 4. The time-resolved microscopic textures (a) for using only vertical alignment material and (b) for using mixed alignment material with RM.

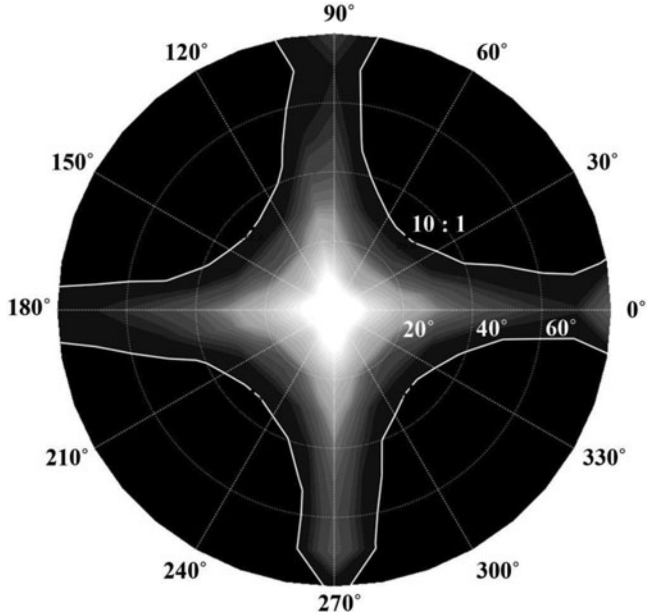

Figure 5. Measured viewing angle characteristics of the fabricated LC cell.

the LC molecules, UV light was exposed to the sample cell with the RM-mixed alignment layer under the applied voltage. The RMs are polymerized at the surface and azimuthal direction of the LCs are defined in the presence of the applied voltage. Figure 3 (b) shows the time-resolved textures of the sample with the RM-mixed alignment layer. Through removing the reorientation processes, the response time was dramatically reduced from 500 to 5 ms.

Figure 5 shows the measured viewing angle characteristics of the fabricated sample. In our proposed LC mode, LC directors are arranged in all azimuthal directions within a single pixel. As a result, 4-fold symmetric viewing angle was obtained as shown in Fig. 5. The white solid line in Fig. 4 represents the contrast ratio of 10:1. It should be noted that when the optical compensation film for the conventional PVA mode was used, the contrast ratio could be dramatically enhanced.

4. Conclusion

In summary, we proposed the vertical alignment LC mode with the wide-viewing angle and the fast response by introducing the x-shaped slit pattern in the pixel electrode and the RM into the alignment layer. The x-shaped electrode patterning for one substrate (pixel electrode) generated the axially symmetric LC configuration and the polymerized RM gave rise to the fast response characteristics through the direct reorientation without reconfiguration process. In addition, by adopting orthogonally circular polarizers, high transmittance was achieved.

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