Viewing angle switching of a liquid crystal panel by using 3-terminal electrode structure

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Abstract

We propose a method to achieve both wide viewing angle (WVA) and narrow viewing angle (NVA) characteristics with a single liquid crystal (LC) panel and a single backlight system by using 3-terminal electrode structure. We could control the viewing angle of a single LC cell by using the horizontal or vertical alignment of LC for the dark state at the front.

1. Introduction

Liquid crystal displays (LCDs) are widely used in various applications because of high resolution, light weight, slim size, and low power consumption. Until now, many kinds of LCD modes have been developed for high quality of displays. Those such as in-plane switching (IPS) and fringe-field switching (FFS) modes have shown inherently wide viewing angle (WVA) characteristics without additional compensation films [1-2]. On the other hand, vertical alignment (VA), twisted nematic (TN), and hybrid-aligned nematic (HAN) modes have asymmetric or narrow viewing angle (NVA) characteristics, so they require additional compensation films to widen the viewing angle [3-4].

Nowadays, the information security becomes more important as the personal information is exposed to others through many mobile devices. So, several methods have been proposed to achieve both WVA and NVA characteristics selectively in LCDs [5-8]. However, conventional approaches require additional processes and materials, because they use dual backlight systems, multiple LC panels, and sub-pixel structure. Dual backlight systems use two kinds of backlight systems, one for WVA mode and the other for NVA mode. Multiple LC layers can be considered, one for gray level control and the other for viewing angle control. In the pixel division method, a complicated fabrication process is needed to pattern the electrode, and the transmittance can be reduced.

In this work, we propose a method for viewing angle control with a single LC panel and a single backlight system to sustain existing cost and fabrication process [9].

2. Principle and Simulation

The general definition of the viewing angle is the maximum angle having a contrast ratio (CR) level over 10: 1, which is affected more by the dark state than the bright state. There are two conditions for the dark state using LC layer between crossed polarizers, of which conditions are the crucial factors to decide the viewing angle of LCD. For the dark state of WVA, the OA of horizontally aligned LC is parallel with the TA of bottom polarizer, as shown in Fig. 1(a). It can be used for WVA characteristics as done in IPS and FFS modes, both modes have inherently WVA characteristics because the dark state is still conserved at off-axes. For the dark state of NVA, we can align the LC vertically, as shown in Fig 1(b). The dark state is obtained by zero retardation of LC at the normal direction, while the leakage of light occurs at off-axes because the vertically aligned LC layer has an optical anisotropy at oblique incidence. Therefore, the VA modes require compensation with negative C films to eliminate the leakage of light at off-axes to achieve WVA characteristics [10-11]. If we could make the dark state in two different ways, one for WVA mode and the other for NVA mode, we can realize both modes with a single panel and maintain cost and process.

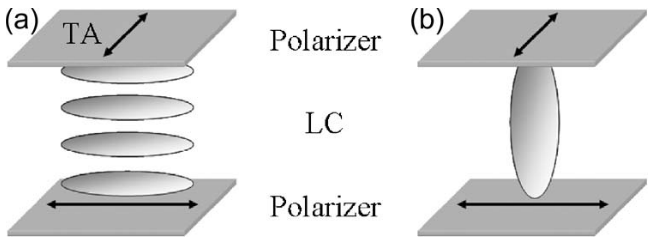
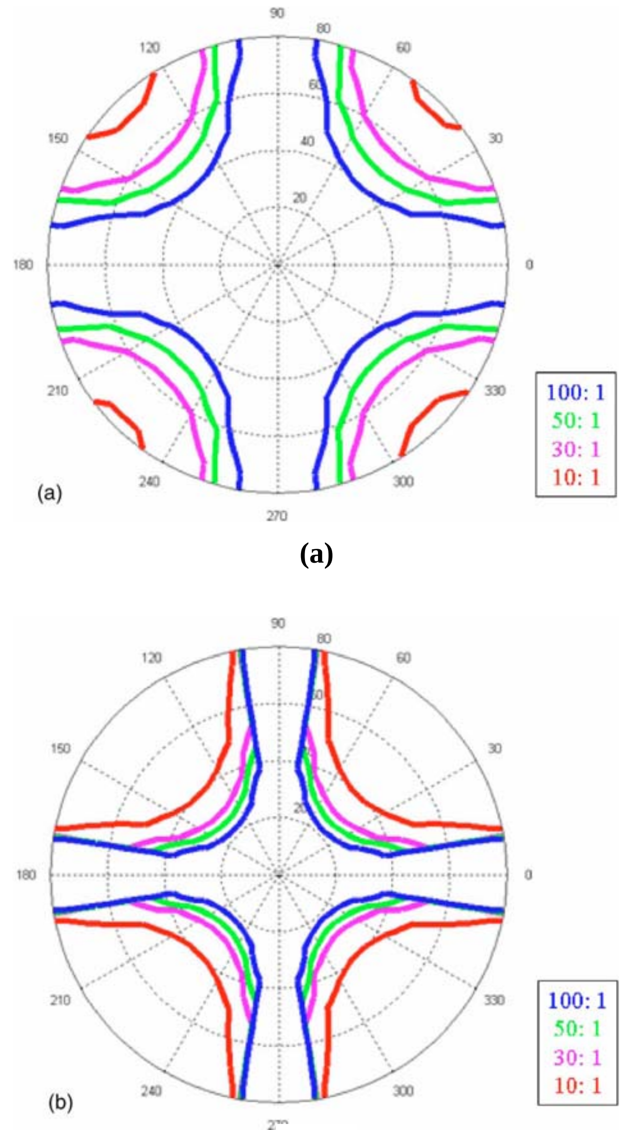


Fig. 1. Two conditions for dark states between crossed polarizers: (a) the LC layer is horizontally aligned along the TA of the bottom polarizer, (b) the LC layer is aligned vertically.

We confirmed the basic characteristics of the proposed structure by numerical calculations following the principle of operation described above. Commercially available software, LCD MASTER, was used for numerical calculation and the result is shown in Fig. 2. Figure 2(a) shows the WVA characteristics and Fig. 2(b) shows NVA characteristics, and the limit of polar angle in both contours is 80°. Blue (innermost), green (inner), magenta (outer), and red (outermost) contour lines indicate the CR limits of 100:1, 50:1, 30:1, and 10:1, respectively. NVA mode shows the leakage of light along the diagonal directions, resulting in a decreased CR compared to WVA mode. In case of WVA mode, almost all the viewing area shows the CR over 10:1. However, in case of NVA mode, the regions having CR level over 10:1 are about 40° along the diagonal directions. There is more changed CR along the diagonal direction than along the TAs of the polarizers. These results come from that the TAs of the two polarizers are not orthogonal at off-axes, and the angle between the TAs of polarizers is smaller or larger than 90° along the directions. Furthermore, the polarization state of incident light is changed due to the optical anisotropy of LC.



(a)

(b)

Fig. 2. Calculated viewing angle characteristics with different dark state conditions: (a) the LC layer is aligned homogeneously, (b) the LC layer is aligned vertically.

3. Experiment

For our experiments, a 3-terminal electrode structure is used, by which we can apply both horizontal field and vertical one as we need [12]. The top electrode is not patterned, while the bottom electrodes consist of the common electrode and grid electrodes, and the overall structure is shown Fig. 3. The horizontal alignment layer (RN-1702, pretilt angle: 1~2°) coated both substrates are antiparallel rubbed at an angle of 5° with respect to the direction of the grid electrodes. The purpose of horizontal alignment is to realize the WVA characteristics at the initial state, and we can apply the vertical field to change the viewing angle characteristics. The width of the grid electrodes and the gap between them are both 4 ㎛ and the thickness of the common electrode, the insulation layer, and grid electrodes of the bottom substrate are 300 nm, 400 nm, and 300 nm, respectively. We made a test cell using the positive nematic LC (MLC-6235-000, Δn: 0.1064, Δε: 7.1, Merck Ltd.) and the cell gap is set by 3.8 ㎛ using ball spacers.

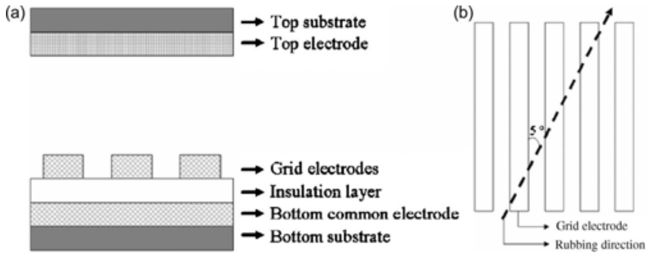


Fig. 3. Overall cell structure: (a) a 3-terminal electrode structure consisting of the top common electrode, the grid electrode, and the bottom common electrode, (b) the angle between the rubbing direction and the grid electrode is 5°.

We can apply a voltage signal between the grid electrode and the bottom common electrode with the top electrode floated to control the transmittance by rotation of OA. To control the viewing angle, we can apply a vertical electric field between the top electrode and the bottom common electrode with the grid electrode floated, for the dark state of NVA mode.

4. Results and Discussion

The TA of the rear polarizer is parallel with the rubbing direction but perpendicular to that of the front polarizer. It shows the dark state for the WVA operation mode when there is no applied electric field. When we apply the horizontal electric field, we can obtain the bright state in the WVA mode and the measured result is shown in Fig 4(a). We can change the operation mode by applying the vertical electric field with 1 kHz square pulses, whose amplitude is 12 V in root-mean-square value. Then, the bright state can be obtained by rotating the LC using the horizontal electric field between the bottom grid and common electrode. The measured result of viewing angle is shown in Fig. 4(b). We used DMS501 (Autronic Melchers Ltd.) to measure the characteristics, and the boundary of the polar angle in both figures is 70° (black bold line).

WVA experimental result shows that almost all the

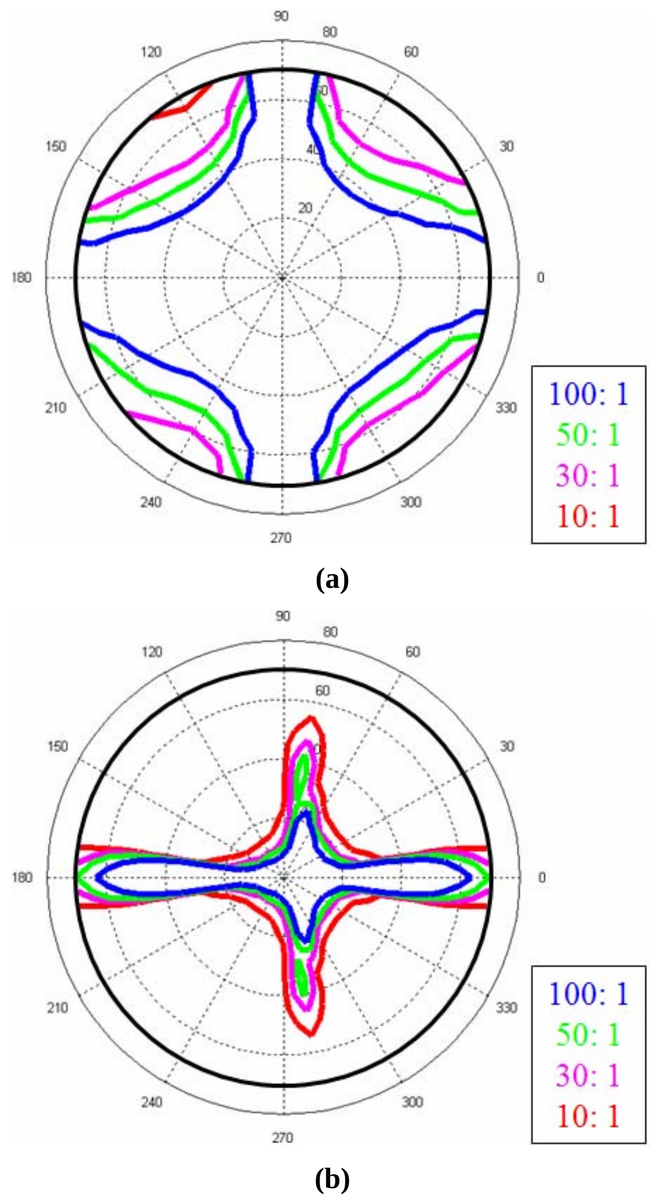


Fig. 4. Measured iso-contrast contours: (a) WVA mode, (b) NVA mode.

viewing area shows the CR level over 10:1, of which result is almost the same with that in Fig. 2(a). However, the result of the NVA mode along the TA directions with the azimuthal angles of 0°, 90°, 180°, and 270° are about 70°, 45°, 70°, and 45°, and along the diagonal directions with the azimuthal angles of 45°, 135°, −135°, and −45° are about 25°, 15°, 15°, and 25°, respectively, which is different from the simulation results in Fig 2(b). Clearly, the widths of the regions having CR level over 10:1 are very narrow along the directions parallel or perpendicular to the rubbing direction, compared to the numerical result.

In numerical calculations, we assumed that all the LC molecules can be aligned parallel to the applied electrical field and there is no anchoring force, by which LC molecules near the surface boundaries are restricted even when a vertical electric field is applied to make the dark state for NVA operation. So the measured viewing angle characteristics are slightly different from the calculated results

4. Summary

We have shown that the viewing angle of LCDs can be controlled by using two dark states, for which the 3-terminal electrode structure capable of both horizontal and vertical switching is employed. In conclusion, we could control the viewing angle of a LC cell with a single panel and a single backlight system.

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