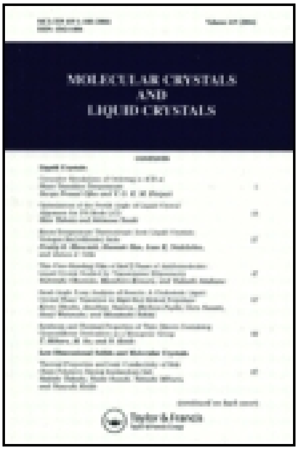

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A method for viewing angle control of a hybrid-aligned liquid crystal (LC) cell is reported. The viewing angle of proposed structure can be controlled by using vertical switching, by which the tilt angle of LC is controlled, while the optical transmittance can be controlled by using horizontal switching, by which the optic axis (OA) of LC can be rotated. A 3-terminal electrode structure composed of the top common electrode, the bottom grid electrodes, and the bottom common electrode is employed for both the vertical switching and the horizontal one.

Keywords: 3-terminal electrode; hybrid alignment; liquid crystal display; viewing angle control

INTRODUCTION

So far, the liquid crystal displays (LCDs) have been widely used as the display devices due to various advantages such as thinness, lightness, and low power consumption. However, the viewing angle characteristics of them were regarded as shortcomings because they modulate the polarization state of incident light rather than emit the light. Progressive researches on such problems improve the characteristics, and now it may not seem to be a problem.

On the other hand, the protection of personal information becomes important as various mobile devices have emerged. Laptop computers, cellular phones, and personal data assistants are used anytime and

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anywhere. Naturally, one may worry about peeping. Hence the narrow viewing angle (NVA) characteristics of display devices are strongly required. However, because people want to share some information with others, the wide viewing angle characteristics (WVA) are also required in the same device. To satisfy such demands, there have been reports on the viewing angle switching of LCDs [1–4]. However, additional components in devices result in the increase in cost. Recently, we proposed the dual-mode switching of single liquid crystal (LC) panel with homogeneous alignment for viewing angle control [5]. In the previous letter, we demonstrated that the inherently WVA characteristics of a homogeneously aligned LC cell can be controlled to be narrowed by using the dual-mode switching.

In this paper, we propose a method for viewing angle control of a hybrid-aligned LC cell. Although LCD modes using hybrid alignment were proposed, previous reports require the compensation to obtain WVA characteristics [6,7]. In this work, we report the viewing angle control method of a hybrid-aligned LC cell, by which the WVA characteristics can be obtained in the cell without any compensation.

PRINCIPLE AND EXPERIMENT

Figure 1 shows the operation principle of the hybrid-aligned LC cell using horizontal switching, of which the rubbing direction is parallel with the transmission axis (TA) of one polarizer and the absorption axis (AA) of the other polarizer. It shows the dark state in the absence of applied voltages. The horizontal switching, by which the optic axis (OA) of LC can be rotated, controls the transmittance of the cell. Inherently the configuration has NVA characteristics, because the leakage

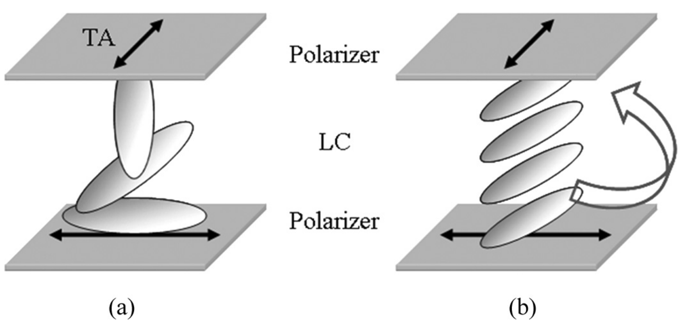

FIGURE 1 Operation principle of hybrid-aligned LC cell using horizontal switching. (a) In the dark state, (b) in the bright state.

of light occurs at off-axes in the dark state except along the direction parallel with the rubbing direction. If the incident light passes through the cell obliquely at the azimuthal angle parallel with the rubbing direction, OA of LC, TA of one polarizer, and AA of the other one are on the same plane, so that the dark state is still conserved. Otherwise, OA of LC is not on the same plane with TA and AA of polarizers, resulting in the leakage of light. In this point, we employ the horizontal alignment of LC in the dark state for WVA mode of an initially hybrid-aligned cell like the in-plane switching and fringe-field switching modes, and that can be obtained by applying a vertical electric field to the negative LC [9,10].

Figure 2 shows the proposed operation of a hybrid-aligned cell. In the NVA mode with conventional driving method, the cell shows the leakage of light in the dark state at off-axes. If the configuration of LC is homogeneous and of which the OA is parallel with the axes

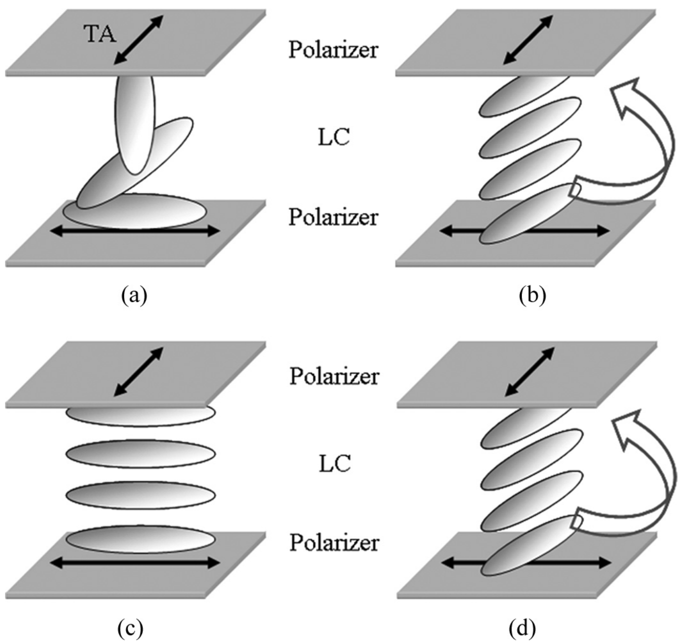

FIGURE 2 Operation principle of the proposed method. (a) Hybrid alignment of LC shows the dark state of NVA mode, (b) the bright state of NVA mode can be obtained by rotating OA of LC, (c) homogeneous alignment of LC can be used for the dark state of WVA mode, and (d) the bright state of WVA mode can also be obtained by rotating OA of LC.

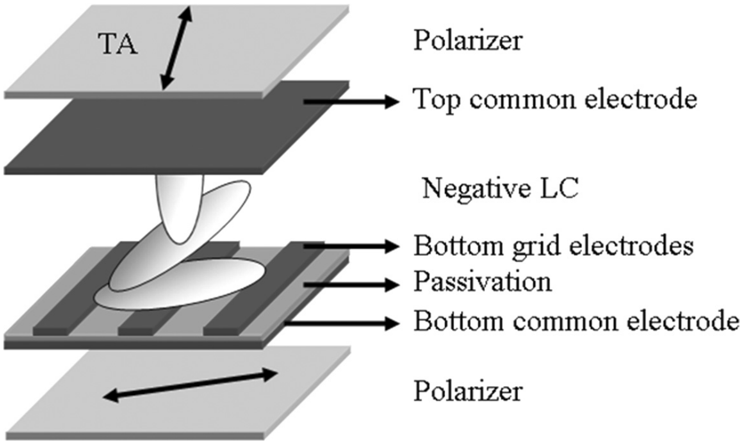

FIGURE 3 Proposed cell structure with hybrid alignment of LC.

of polarizers, it shows the dark state at the normal direction as well as at off-axes, so that we can use it as the WVA mode. In both operating modes, the bright state can be obtained by rotating OA of LC. Vertical switching is required to control the viewing angle, and horizontal switching is also required to control the transmittance.

To realize such configurations, a 3-terminal electrode structure is employed to switch both horizontally and vertically [10]. Figure 3 shows the overall cell structure including such an electrode structure. The negative LC (MDA-01-2306, Δn: 0.1204, $\Delta\varepsilon$: -5, Merck Ltd.) is inserted between vertical-alignment-layer-coated top substrate and horizontal-alignment-layer-coated bottom substrate, of which cell-gap was fixed to 4 μm by the ball spacer. Rubbing directions are anti-parallel, and they form an angle of 85° with grid electrodes. Both of the width and the gap of grid electrodes are 4 μm. WVA characteristics are obtained by applying a vertical electric field, resulting in the horizontal alignment of negative LC. The bright state is obtained by applying a horizontal electric field between bottom grid and bottom common electrodes, by which OA of LC is rotated.

RESULTS AND DISCUSSION

Figure 4 shows electro-optic characteristics of a fabricated cell. To avoid the decrease in transmittance resulting from the horizontal component of electric field, we applied a complex electric field for the bright state [6,7]. The voltages with 1 kHz square pulses are applied

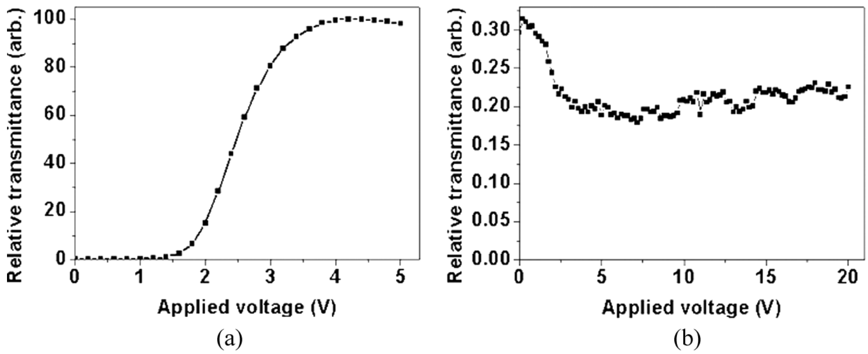

FIGURE 4 Electro-optic characteristics at the normal direction. (a) The voltage-dependent transmittance curve with varying the amplitude of complex electric field with 1 kHz square pulses and (b) the transmittance at the normal direction in the dark state with varying the amplitude of vertical electric field with 1 kHz squares pulses.

between the grid electrodes and the bottom common electrode, while the top common electrode is shorted to the bottom common electrode. Figure 4(a) shows the voltage-dependent transmittance characteristics of a cell. To arrange LC homogeneously for the dark state of WVA mode, we can apply voltages between the top common electrode and the bottom common electrode. It shows still the dark state in the normal direction, and the transmittance at off-axes is reduced. However, since the rubbing direction and the grid electrode form a specific angle, the leakage of light occur due to the fringe-field. Figure 4(b) shows electro-optic characteristics of a fabricated cell with the amplitude of vertical voltages as parameters. It seems that the transmittance in the dark state is lowered by applying a vertical electric field. However, generally it is not easy to accord the rubbing direction of a hybrid-aligned cell with the axes of crossed polarizers, accordingly we can agree just that the transmittance in the dark state is seldom changed by vertical switching.

Figure 5 shows the measured viewing angle characteristics of a hybrid-aligned cell with 3-terminal electrodes. Each iso-contrast contour plot was obtained by varying the amplitude of a vertical electric field with 1 kHz square pulses in the dark state. The bright state was obtained by applying 4.4 V between the bottom grid and the bottom common electrode, while the bottom common electrode is shorted to the top common electrode. The viewing angle becomes wider as we increase the amplitude of vertical voltages. When 20 V is applied, the viewing angles of horizontal and vertical directions cover almost all

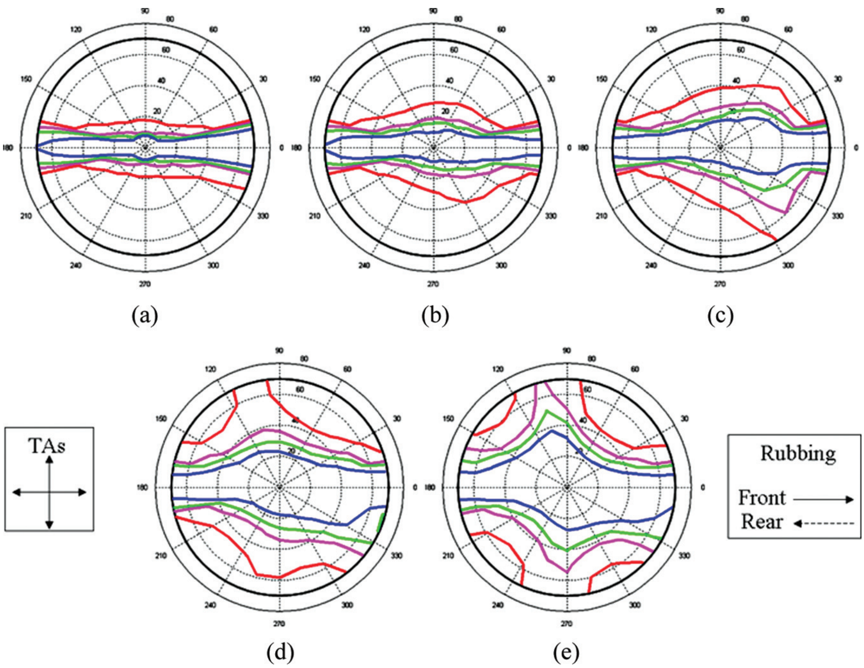

FIGURE 5 Viewing angle measurement results of a fabricated cell. (a) Without vertical electric field in the dark state, (b), (c), (d), and (e) with vertical electric field with amplitude of 3 V, 5 V, 10 V, and 20 V, respectively. The bright state was obtained by applying 4.4 V between the grid electrode and the bottom common electrode, while the top common electrode is shorted to the bottom common electrode.

ranges even when no compensation is included. Although the infinite amplitude of vertical voltage is required to align LC homogeneously, we can see that the viewing angle of fabricated device with proposed structure is sufficiently widened.

Conventional hybrid alignment modes require compensation films to enhance the viewing angle characteristics. The leakage of light occurs at off-axes in the dark state of a hybrid-aligned cell except along the rubbing direction, because the tilt angle of a hybrid-aligned LC is continuously changed. Previous methods compensate a LC layer with retardation films. However, since the specification of those may be dependent on the cell conditions such as pre-tilt angle, retardation value, it may not easy to do. The vertical bias method can be economic, efficient, and potential candidate to change the viewing angle characteristics of the hybrid-aligned mode without additional films.

CONCLUSION

The vertical electric field controls the tilt angle of LC, resulting in the light leakage at off-axes in the dark state, which is the crucial factor of viewing angle. The inherently NVA of a hybrid aligned LC cell is easily controlled by vertical switching, and the viewing angle of NVA mode is widened without additional compensation. To employ horizontal switching for the control of transmittance, the 3-terminal electrode structure is employed for these needs.

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