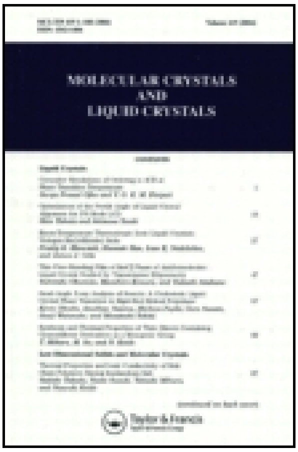

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Mixed Field Controlled-Vertically Aligned Nematic Mode with High Transmittance

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Mixed Field Controlled-Vertically Aligned Nematic Mode with High Transmittance

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We propose a new LCD mode, mixed field controlled vertically aligned nematic (MFVA) mode to improve demerit of patterned vertically aligned nematic liquid crystal (PVA) mode that has lower transmittance due to flat electrical potential in vicinity of central region between top and bottom slits. The proposed mode which produces higher transmittance and faster response speed than PVA mode is composed of the two stripe type ITO common electrodes, wholly ITO coated common electrode, and wholly ITO coated pixel electrode. The simulated results show that the proposed LCD mode has excellent electro-optical characteristics.

Keywords Electro-optic characteristics; fast response time; high transmittance; vertically aligned nematic LCD mode

1. Introduction

Over the past 10 years, several thin film transistor (TFT)-liquid crystal display (LCD) technologies for example twisted nematic mode (TN) [1], in-plane switching (IPS) mode [2], fringe field switching (FFS) mode [3], vertical alignment (VA) type nematic modes [4], and optically-compensated bend (OCB) mode [5–7], etc. [8–14] have been extensively developed for several display applications which needs excellent electro-optic properties. Among the several proposed LCD modes, VA-type LCD modes such as multi-domain vertical alignment (MVA) nematic mode, advanced super view (ASV) nematic mode, and patterned vertical alignment (PVA) nematic mode have been attractive LCD display modes. They possess many merits as high quality display, such as rubbing free process without surface contamination, wide

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viewing angle with compensation films, low driving voltage, and high contrast ratio at normal direction. Due to these merits, VA-type modes are being applied widely to various LCD applications such as TV, monitor, electronic mobile phone, etc. However, they have also demerits such as slow rising speed and low transmittance caused from the absence of preference direction in LC molecules behavior driven from matching between electric field direction and initial LC alignment in vicinity of the middle region of electrodes producing nearly vertical field.

In order to solve these problems, precisely to give preference direction in LC molecules behavior to the middle region of electrodes, and so to improve the rising speed, Kim *et al.* proposed polymer stabilized PVA (PS-PVA) mode using reactive mesogen (RM)-dopped LC-mixture to produce an appropriate pretilt of LCs in pixels [15]. The pretilt is driven from fixation of surface LCs due to the solidification of RM huddled on the surface by UV exposure under a proper electric field which gives some slope to surface LCs. And Lee *et al.* presented surface controlled patterned vertical alignment (SC-PVA) mode using RM-dopped polyimide-mixture instead of LC to produce an appropriate pretilt of LCs in pixels [16]. Then, the pretilt and azimuthal angles are determined and memorized on the LC alignment layer by polymerization of doped RM monomer through UV exposure under a proper electric field. However, these LC alignment techniques may induce degradations of image quality in a viewpoint of long term stability since the RM could be acted as an impurity. Furthermore, the generation of initial pretilt at VA type mode may produce dark leakage, and resultantly it reduces contrast ratio (CR).

In this paper, we propose mixed field controlled vertically aligned nematic (MFVA) mode characterized by two stripe type common electrodes on the bottom and the top substrates each other. Here, the stripe type common eletrodes play important role to generate horizontal electric field that prevents the absence of preference direction for LC molecules behavior in vicinity of the middle region of electrodes. The proposed MFVA mode can improve response speed and transmittance remarkably. Consequently, it is useful to upgrade the LCD display quality.

2. Pixel Structure of the Proposed LC Mode

Figure 1(a) and (b) show LC director behaviors without and with electric field in the cell structure of typical PVA mode. As shown in Figure 1(b), we can know that the electric field in region indicated as circle mark is nearly vertical. Due to the vertical electric field of this region, vertically aligned LCs are confused on the decision of azimuthally preference direction, so it gives rise to disclination formation of LCs. For that reason, the response speed of PVA mode slows at rising time. In addition, we cannot widen the distance between the slit of the top substrate and it of the bottom substrate, which can generate high transmittance, since it aggravates the disclination formation of LCs to wider region.

In order to improve this issue, we designed a new type of electrode structure in the VA mode. Ultimatly, we focused on tilting slightly the vertical electric field between the top and the bottom electrodes. Figure 2 shows the schematic diagram of the unit LC cell structure of the proposed LCD mode. Firstly, the wholly indium-tin-oxide (ITO) coated electrodes are positioned on both glass substrates. The wholly ITO coated electrode on the bottom substrate is the pixel electrode connected with TFT, and it on the top substrate becomes the first common electrode. The passivation layers (insulator) are located on them to prevent electrical short between the

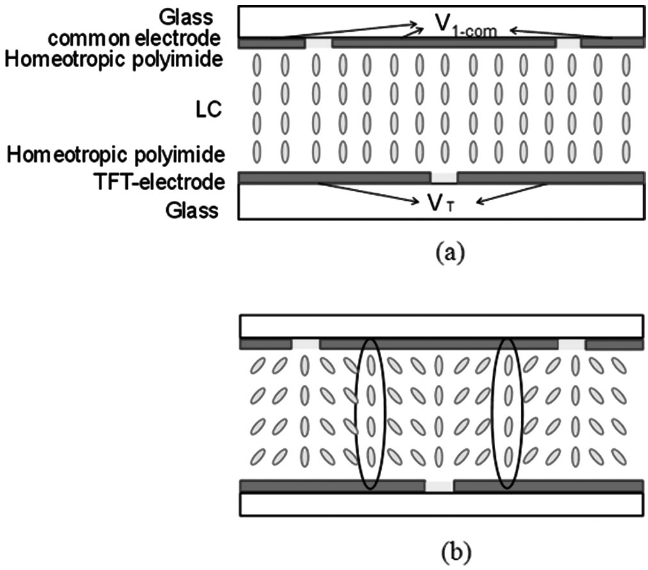

Figure 1. (a) The cell structure of the typical PVA mode and (b) the schematic showing LCdisclination formation due to the vertical electric field in the central region between top slit and bottom slit.

pixel electrode (TFT-electrode, V_T) and the stripe type third common electrode ($V_{3\text{-com}}$) on the bottom substrate and between the stripe type first common electrode ($V_{1\text{-com}}$) and the stripe type second common electrode ($V_{2\text{-com}}$) on the top substrate. In this electrode structure, the electrical potential difference between the pixel and the third common electrodes induces a horizontal electric field, while the electrical potential difference between the pixel and the first common electrodes induces a vertical electric field. In addition, the electrical potential difference between the first common and the second common electrodes produces also a horizontal electric field even though it is weak field. Consequently the vertical electric field between the pixel and the first common electrodes can be tilted by the second and the third common electrodes producing the horizontal electric field.

We apply constant voltages to the first, second, and third common electrodes. However the electric polarity of the second and the third electrods should be changed

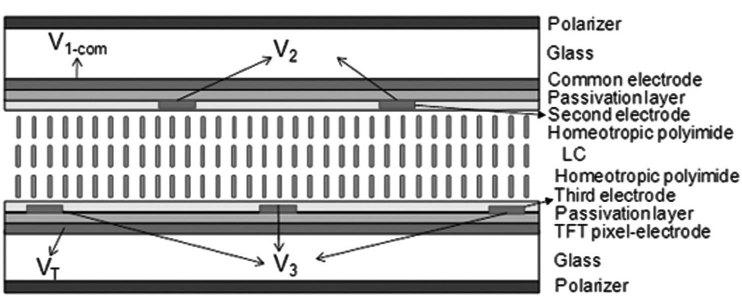

Figure 2. The schematic diagram of the unit LC cell structure of the proposed MFVA mode including three common electrodes and one pixel electrode.

each and every flame and they should have always apposite polarity each other to maintain same electric field direction within an LC domain.

3. Simulated Result

To examine numerically the electro-optics of our proposed VALC mode, we use a commercial LCD simulator from Techwiz LCD. The LC material and the cell thickness used for simulation are MLC-6608 (Merck) which has $\Delta n = 0.083$ and 3.5 μm, respectively.

To compare our proposed MFVA mode with PVA, firstly we simulated PVA mode. Figure 3 shows the simulated results of LC director behaviors and equipotential lines under electric field of typical PVA mode. As shown in Figure 3, the electric field in region indicated as circle mark is nearly vertical even in low voltage, 2 V. The more voltage increases, the more vertical the electric field becomes as shown in Figure 3(b). The vertical electric field of this region confuses vertically aligned LCs on the decision of azimuthally lying down direction, so called disclination formation of LCs. The response time of PVA mode is long due to this reason. Here, the distance between slits is 30 μm and the width of slit is 10 μm.

Subsequently, we simulated mixed field-controlled vertical alignment (MFVA) nematic mode as the electrode structure shown in Figure 2. In our simulation, the constant voltages to the first, the second, and the third common electrodes are 0 V, 1.5 V (−1.5 V), and −1.5 V (1.5 V), resultantly to induce a horizontal electric field in pixel. Here, 1.5 V is under threshold voltage of MLC-6608. The voltage V_T of the pixel electrode connected with TFT is variable to 10 V from 0 V. The horizontal fields between the pixel and the third common electrodes and between the first and the second common electrodes remove the absense of azimuthal preference direction caused from vertical field between the pixel and the first common electrodes. The voltages of each common electrodes can be optimized according to cell thickness, LC material, the distance between the stripe type electrodes, etc. Here,

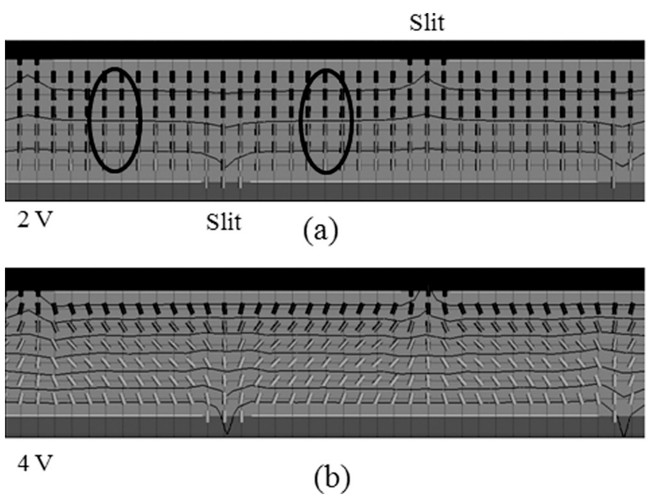

Figure 3. LC director behavior under 2 V and 4 V of PVA structure with 30 μm:10 μm.

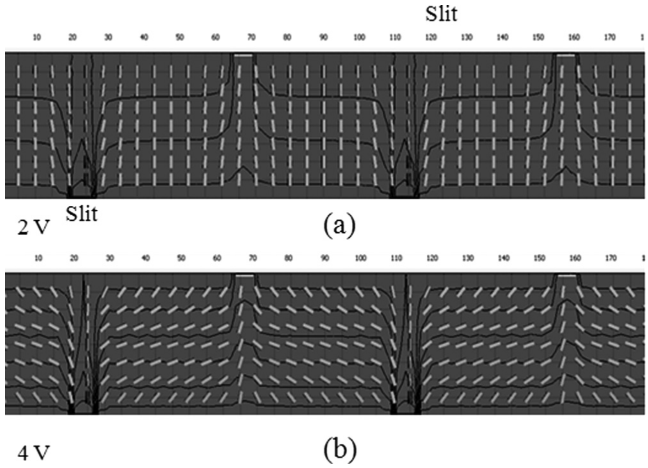

Figure 4. LC director behavior under 2 V and 4 V of MFVA structure with 40 μm:5 μm.

the distance between the bottom and the top stripe type electrodes is 40 μm and the width of the stripe type electrode is 5 μm.

Figure 4 shows LC director behavior and equipotential under electric field of the proposed MFVA mode. As expected, it shows obviously that the equipotential lines are not flat when V_T is 2 V and 4 V. It means that vertical field generating the absense of azimuthal preference direction of LCs is tilted slightly in between the stripe electrodes even though the distance between the bottom and the top stripe type electrodes is 40 μm which is wider than it of typical PVA mode with 30 μm. As a result, the MFVA mode can lead to faster response speed. Moreover, we can enlarge the distance between the stripe electrodes to increase transmittance.

Figure 5 shows LC director behavior and equipotential line under 1 V and 3 V of MFVA mode when the distance between the bottom and the top stripe type electrodes is 50 μm and the width of the stripe electrode is 5 μm. Even though the distance is extended, equipotential line is still tilted. We also are able to confirm that higher transmittance come out in the electrode structure of the 50 μm distance.

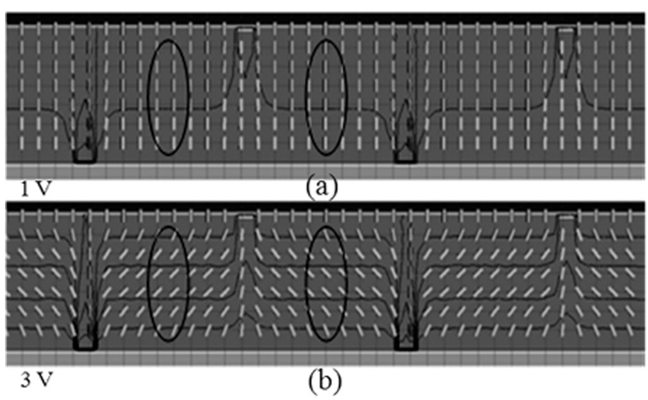

Figure 5. LC director behavior under 1 V and 3 V of MFVA structure with 50 μm:5 μm.

Figure 6 is LC director behavior and transmittance according to time of MFVA structure with 40 μm:5 μm and PVA structure with 40 μm:10 μm under 3 V. They show that the LC directors in vicinity of the middle region of electrodes of MFVA mode respond to electric field more rapidly, compared with PVA mode. It is caused by horizontal electric field produced from voltage difference between the pixel and the third common electrodes.

Figure 7 shows comparison of voltage-transmittance curves of MFVA mode with electrode structures of 5 μm:40 μm and 5 μm:50 μm with respect to typical PVA mode with 10 μm:30 μm. As we expected, as distance between the stripe type electrodes increases, the transmittance also is increased slightly. As a result, all the two structure shows higher transmittance than the typical PVA mode. MFVA mode can have transmittance increased by 7% and 12% compared with PVA mode.

Finally, to examine gamma characteristics when the top and the bottom electrodes are misaligned, we compared V-T curves at MFVA mode with 5 μm misalignment between the top and the bottom stripe type electrodes and with alignment matching. Figure 8 shows even though 5 μm misalignment in MFVA mode occurs, the V-T curve is not changed nearly. Eventually, the MFVA mode is useful to apply to high quality LCD performance.

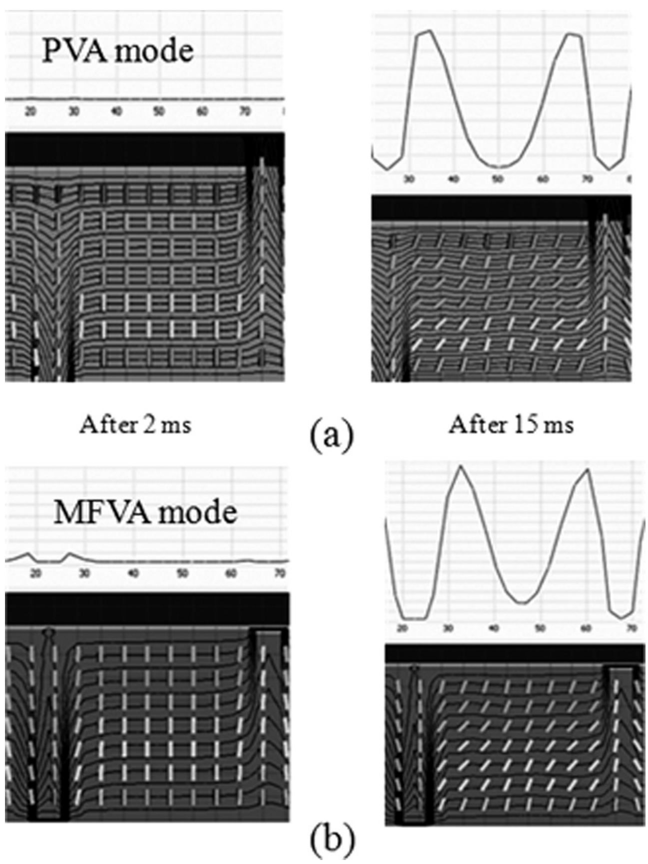

Figure 6. LC director behavior and transmittance according to time of MFVA structure with 40 μm:5 μm.

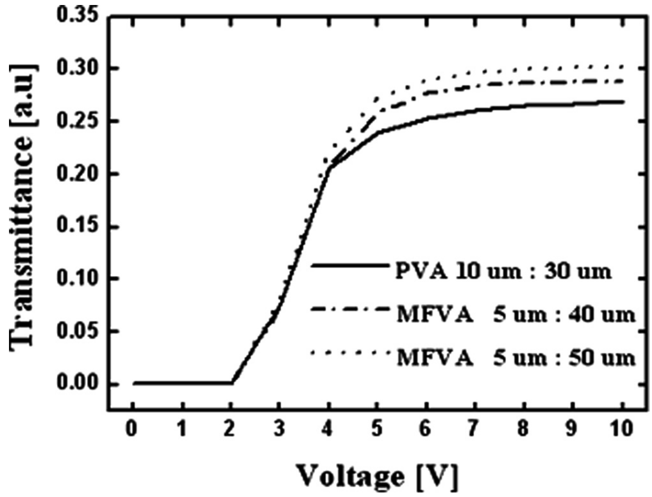

Figure 7. Comparison of voltage-transmittance curves of MFVA mode with electrode structures of 40 μm:5 μm and 50 μm:5 μm with respect to typical PVA mode with 30 μm:10 μm.

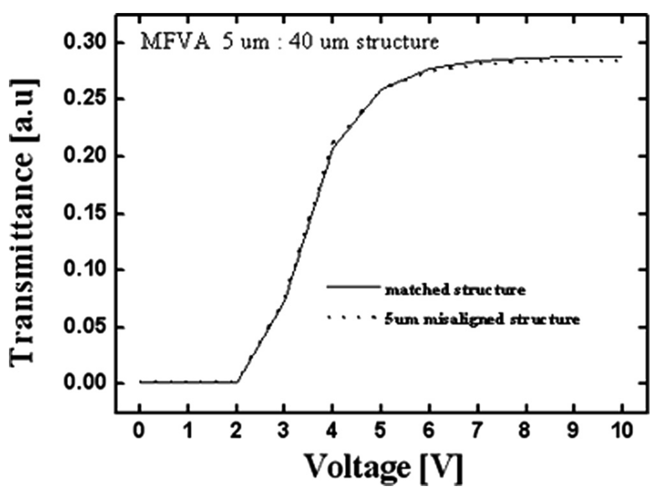

Figure 8. Comparison of V-T curve at 5 μm misalignment between the bottom and the top stripe type electrodes.

4. Conclusions and Perspectives

In this paper, we presented as a new LCD display mode, mixed field-controlled vertical alignment (MFVA) nematic mode characterized by additional stripe type common electrodes which play important role to generate horizontal electric field that prevents the absense of azimuthal preference direction of LC molecules in vicinity of the middle region between the bottom and the top stripe type electrodes. The proposed MFVA mode can improve response speed and transmittance remarkably. Consequently, MFVA mode is useful to apply to high quality LCD performance.

The results of simulation of the proposed MFVA mode shows that an excellent electro-optic characteristics are exhibited. So we can expect that this is applicable to LCD industry. However, there remain some demerits in our MFVA LCD mode. To change the electrical polarity of the second and the third common electrodes, it may need an additional converter including more complex driving circuit. Therefore, as an our future research work, we will focus on simplifing driving circuit.

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