P-12: A Novel Electrode Design for High Transmittance In-plane Switching Liquid Crystal Displays

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Abstract

We propose a new electrode design to enhance the transmittance of a conventional in-plane switching (IPS) mode liquid crystal display (LCD). In this high transmittance IPS (HT-IPS) mode, both substantial horizontal electric fields and fringe fields are generated simultaneously in different regions to reorient the liquid crystal directors. The HT-IPS mode can reach a transmittance >90% of a twist-nematic (TN) cell using both positive and negative LC materials, while it inherently shows a wide-viewing angle as well.

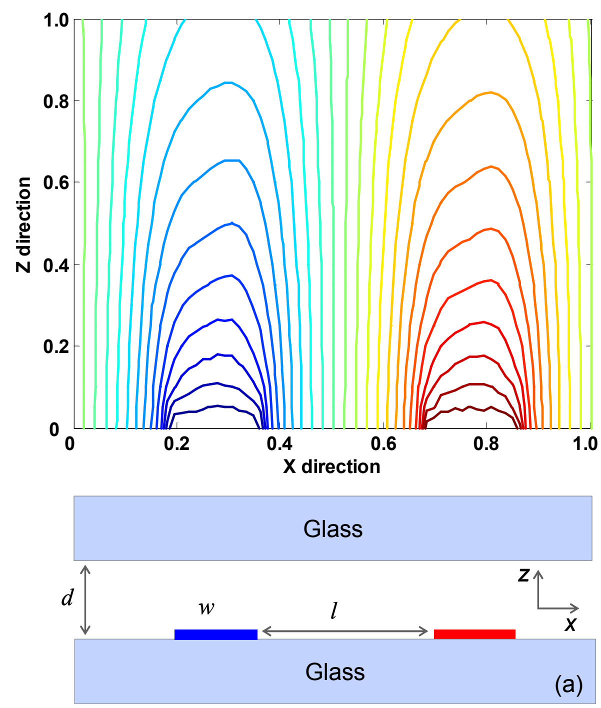
1. Introduction

Liquid crystal display has been extensively employed for computer monitors and TVs owing to the continuous improvement in its image quality. Among various LCD technologies, the IPS mode [1] is one of the mainstream technologies developed for wide-viewing angle. In a typical IPS cell, the electrodes are formed on the same substrate and in-plane electric fields induced by them twist the LC directors to generate light transmission through the crossed polarizers. However, due to the strong vertical electric fields existing above the electrode surface, the LC directors in these regions mainly tilt rather than twist. As a result, the transmittance above the electrodes is greatly reduced. Overall, the conventional IPS mode has a light efficiency about 76% of that of a TN cell, when a positive dielectric anisotropy ($\Delta\varepsilon$) LC material is used. Although using a negative $\Delta\varepsilon$ LC in the IPS mode could enhance the light efficiency to ~85%, the tradeoff is the increased driving voltage.

In this paper, we propose a new electrode design to enhance the light efficiency of IPS cell using both positive and negative $\Delta\varepsilon$ LC materials. The intrinsic wide-viewing angle of the IPS cell is preserved.

2. Device Configuration

Figures 1(a) and 1(b) show the device configurations of a conventional IPS cell and our new high transmittance (HT) IPS design. The calculated on-state equal potential distributions are also included for comparison. From Fig. 1(a), there are substantial horizontal electric fields between the pixel and the common electrodes, while strong vertical electric fields exist above electrode surfaces. Consequently, the LC directors will mainly tilt rather than twist above the electrode surfaces, resulting in a low transmittance there. In our design, to enhance the transmittance in these regions, each common electrode in Fig. 1(a) is replaced by an electrode group with a pixel electrode surrounded by two common electrodes underneath, and each pixel electrode in Fig. 1(a) is substituted by another electrode group with one common electrode adjoined by two pixel electrodes, as shown in Fig. 1(b). More specifically, the electrode width w_1 and w_2, and distance l_1 between adjacent electrodes within each group is kept less than the LC cell gap d, and the distance l_2 between two electrode groups is larger than the cell gap d. With this electrode configuration, fringe fields with both horizontal field components are generated within each electrode group and substantial horizontal electric fields flourish between the electrode groups, as shown in Fig. 1(b). This configuration fuses the electric field profile both from the conventional IPS mode and the fringe-field switching (FFS) mode [2]. Consequently, the LC directors throughout the whole cell can be rotated to achieve a high transmittance.



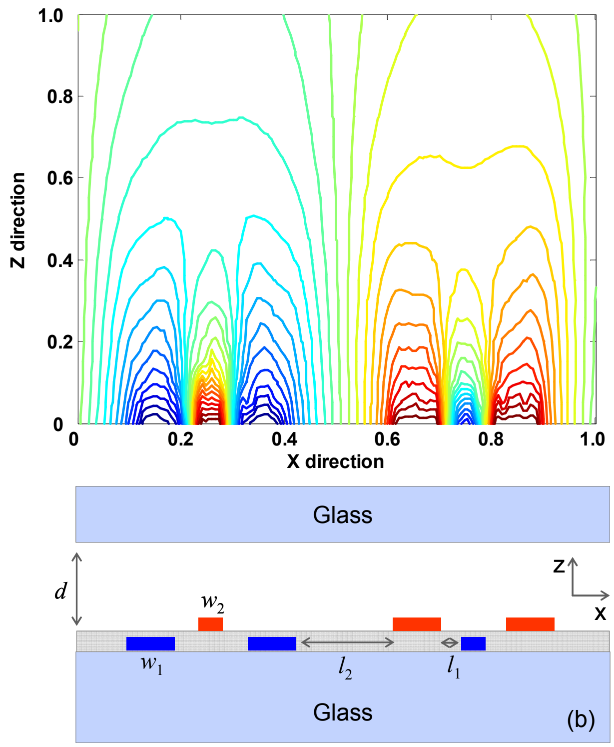


Fig.1. Structure and potential profile of (a) an IPS cell and (b) a HT-IPS cell.

3. Results

To validate the concept, we simulated the HT-IPS cells using both positive and negative Δε LC materials by the 2dimMOS software [3]. For the cell using a positive Δε LC, MLC-6692 with K_{11}=9.2 pN, K_{22}=6.1 pN, K_{33}=14.6 pN, Δε=10.3, n_o=1.4771 and n_e=1.5621 at λ=589 nm is employed, while MLC-6608 with K_{11}=16.7 pN, K_{22}=7.0 pN, K_{33}=18.1 pN, Δε=–4.2, n_o=1.4748 and n_e=1.5578 at λ=589 nm is taken for the negative Δε cell. Detailed cell parameters are listed in Table I.

TABLE I. Parameters used in the HT-IPS cells.

	+Δε LC	-Δε LC
d	4.4 μm	4.4 μm
rubbing angle	80°	10°
pretilt angle	2°	2°
w_1	2 μm	2 μm
w_2	1 μm	2 μm
l_1	1 μm	1.5 μm
l_2	6 μm	5 μm

Figure 2 shows the transmission with respect to the position in a single electrode period for HT-IPS cells using a positive Δε LC and a negative Δε LC. The corresponding electrode position is also included in the figure as a reference. The averaged light efficiency for cells using a positive Δε LC and a negative Δε LC is ~91% and 96% of that of a TN cell in accordance with the top and bottom figures. The transmittance in both LC cells is nearly flat except in the regions between electrode groups, where horizontal fields dominate. And within each electrode group, fringe fields having rich horizontal components twist the LC directors and give rise to a high transmittance as well. As we can see, the tilt of positive Δε LC directors above electrode surfaces causes some low transmittance kinks in the positive Δε cell. As the tilt is suppressed in the cell using a negative Δε LC material, a higher light efficiency is obtained.

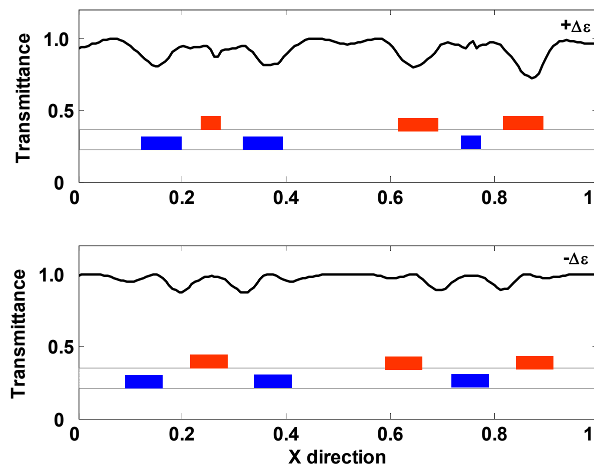


Fig.2. Transmittance curves for HT-IPS cells with +Δε and -Δε LC's.

We further study the voltage dependent transmittance (V-T) curves of the conventional IPS and the HT-IPS modes, because they have the same initial homogeneous alignment and the electrodes are formed on one substrate. The electrode width *w* in the IPS mode in Fig. 1(a) is 4 μm with a separation length *l* of 8 μm for both cells using a positive Δε LC and a negative Δε LC. And the cell gap *d* is kept at 4 μm and 4.4 μm for the positive and negative Δε LC cells, respectively. The electrode and cell dimensions for the HT-IPS designs are the same as those listed in Table I.

Figure 3 shows the corresponding calculated V-T curves. The transmittance reaches 91% at around 5.5 V_{rms} for the positive $\Delta\varepsilon$ cell and 96% at around 6.0 V_{rms} for the negative $\Delta\varepsilon$ cell, respectively. For the IPS cells, it reaches 76% in the positive $\Delta\varepsilon$ LC cell at around 4.5 V_{rms}, and 88% in the negative $\Delta\varepsilon$ cell at around 7.0 V_{rms}. The overall transmittance in the HT-IPS cells is much higher than that in the IPS cells.

Figures 4(a) and 4(b) show the iso-contrast plots for the IPS cell and HT-IPS cell using a positive $\Delta\varepsilon$ LC. And the viewing angle performance for the structures using a negative $\Delta\varepsilon$ LC material is investigated in Figs. 5(a) and 5(b). For comparing the intrinsic viewing characteristics, no compensation film was employed. Because the LC directors have similar homogeneous alignment at the initial voltage-off state, their iso-luminance at the voltage-on state determines the iso-contrast performance. As expected, the HT-IPS cells have a larger viewing angle than the conventional IPS cells, regardless of the LC materials used. For TV applications, wide-viewing angle is critical. Various film compensation schemes of IPS and HT-IPS modes have been considered [4]. Other similar electrode designs to fuse the IPS and FFS modes are also proposed to improve the transmittance of the conventional IPS mode [5, 6].

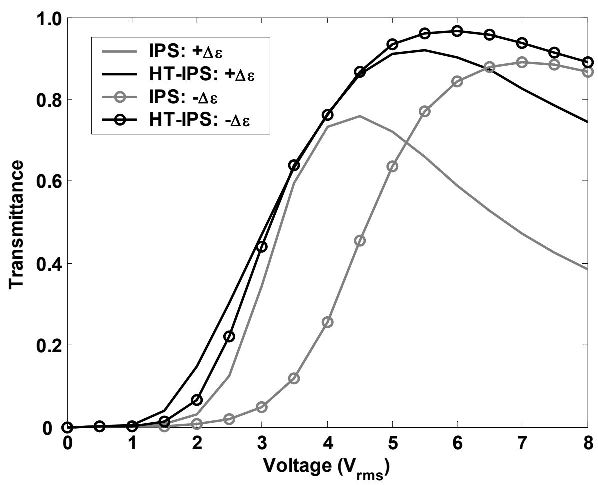


Fig.3. The simulated VT curves for IPS and HT-IPS cells with +Δε and -Δε LC materials.

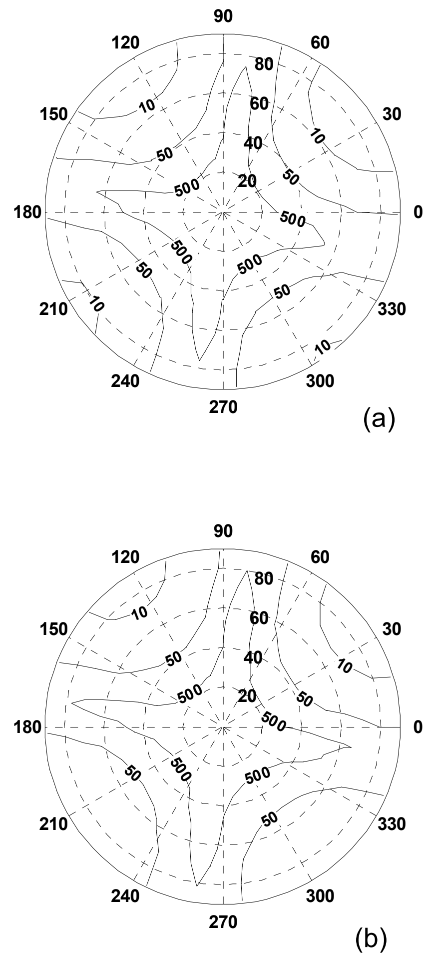
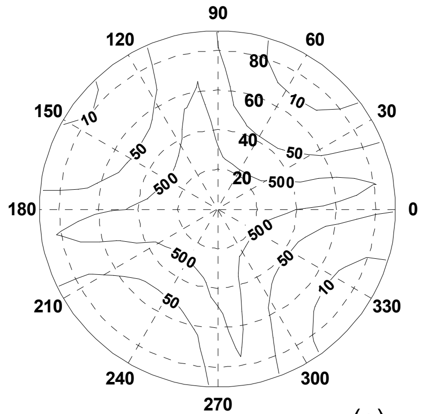
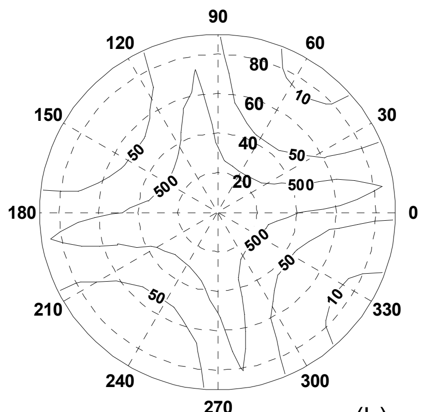


Fig.4. Iso-contrast plots for (a) an IPS cell and (b) a HT-IPS cell using a +Δε LC.



(a)



(b)

Fig.5. Iso-contrast plots for (a) an IPS cell and (b) a HT-IPS cell using a -Δε LC.

4. Conclusion

We have developed a new electrode configuration to enhance the transmittance of a conventional IPS mode. This design can reach above 90% light efficiency for cells using both positive and negative Δε LC materials, while inherently holding a wide-viewing angle. This design shows great potential for future applications in LCD monitor and TVs.

5. Acknowledgement

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6. References

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