A Novel Approach to Suppress the Gamma Distortion in Oblique Viewing Angles for Polymer-stabilized Vertical Alignment Mode

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Abstract

The color shift of 4-domain polymer-stabilized (PS)-vertical alignment (VA) in oblique viewing directions is a severe problem so that a 8-domain PS-VA is required to suppress the color shift. We propose a novel approach to form the 8-domain by controlling surface polar anchoring energy and patterned electrode width in two regions of a pixel. The gamma distortion index (GDI) was reduced by about 23% and 8% compared to standard 4-domain at polar angles of 30º and 60º at an azimuthal angle of 0º, respectively.

Author Keywords

vertical alignment; 8-domain; off-axis picture quality; color shift

1. Introduction

The liquid crystal display (LCD) is a very prominent in the display technology due to its easy and cost ineffective manufacturing methods. Lot of research has been gone through the LCD technology and enormous techniques have been adopted to bring down the cost and enhance the high quality display. Lot of LC modes were proposed to modify the external filed profile, such as in-pane switching (IPS) [1], fringing field switching (FFS) [2], and vertical Alignment (VA) . Among all LC display modes, the VA mode has widely been used in LCD television (TV) due to its unusual properties like high transmittance, high contrast ratio. On other hand few unsolved drawbacks of VA mode remains challenging, such as color shift and narrow viewing angle, gamma distortion property that originated from the perpendicular alignment to the cell substrate. There were few reports that attempted to overcome Multi-Domain Vertical Alignment (MVA) [3] and Patterned Vertical Alignment (PVA) [4]. By adopting this mode, viewing angle was improved. The PVA structure was further modified as 4-domain. The viewing angle was improved by further dividing each pixel to produce voltage difference such that it brings the differences in liquid crystals behavior, this alignment is known as Super-Patterned Vertical Alignment (SPVA) [5]. According to the driving method the 8-damain mode can be classified as many types. Capacitor-Coupling Type (C-C Type) [6], Two Transistor Type (T-T Type) [7]. Very recently the Charge Shared type (CS Type) [8] was proposed by introducing the gate line and two data lines half (Half-Gate Two Data, HG-2D) [9]. Resistivity Division Type (RD-Type) by a transistor and a voltage division was also reported [10]. However, aperture ratio is decreased due to additional data lines while manufacturing cost is increased because of transistor design in 8-domain mode. In order to overcome these problems, we proposed a model to form 8-domain by controlling the width as well as spacing of main and sub region electrodes in combination with surface polar anchoring of vertical alignment.

2. Experiment and Result

In order to test feasibility of the proposed 8-domain PS-VA mode, we used a three-dimensional simulation program (Techwiz LCD, SANAYI system Co.) to simulate electro-optical properties of the proposed structures. For calculations, the LC material used in this study had a negative dielectric anisotropy ($\Delta\varepsilon$) of -4 and a birefringence (Δn) of 0.0816 at 589.3nm. The surface pretilt angle in LC orientation was assumed to be 89^{o} which can be achieved by curing reactive monomer like in the PS-VA mode. The top substrate in the PS-VA mode has a plane shape of indium-tin-oxide (ITO) layer, and the bottom substrate had fish-bone-shaped ITO electrode, as shown in Fig. 1. The pitch of patterned electrode in each domain was kept constant while the electrode width (w) and the distance between the electrodes (l) were varied.

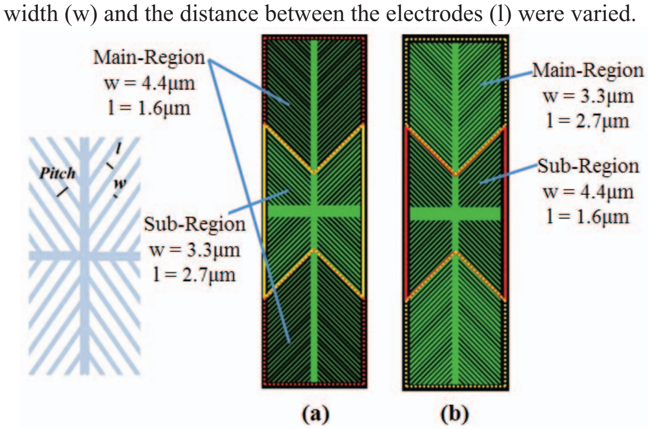

Figure 1. Pixel electrode structure with two regions controlled anchoring energy: (a) case 1/case 2, (b) case 3.

We calculated a voltage-dependent transmittance according to the electrode width and separation, and magnitude of polar anchoring energy (W_θ) at fixed azimuthal anchoring energy (W_φ) for normal 4 domain, as shown in figure. 2. The anchoring energy of the alignment layer can be controlled by the degree of polymerization of monomer in the PS-VA mode and also mixing planar alignment layer with vertical alignment layer [11]. The threshold voltages (V_{th}) defined as a 10% transmittance change from a dark state are 2.9V and 3.0V for *l* equal to 3.3µm and 4.4µm electrodes, respectively. The V_{th} value of 3.3µm electrode is 0.1V lower than that of 4.4µm electrode, that is, the shorter the electrode separation the stronger the electric field of the vertical component applied to the LC. The V-T curves for different polar anchoring energies revealed that the low anchoring energy sample was exhibiting the low V_{th} and low operating voltage (V_{op}). By adjusting the polar anchoring energy, we observed a decreasing tendency in V_{th} with polar anchoring energy.

Once we confirmed V-T curves are strongly related to electrode structure and magnitude of anchoring energies, we combined both factors such that W_θ with 10^{-4}N/m is applied to the region with (*l*, *w*) equal to (3.3, 2.7) in µm, while W_θ with 10^{-3}N/m is applied to

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the region with (l, w) equal to (4.4, 1.6) in μm, and V-T curves are calculated as shown in Fig. 3. As expected, the first combination exhibits a lower threshold voltage by 0.4V and higher transmittance than those in the latter combination, as shown in

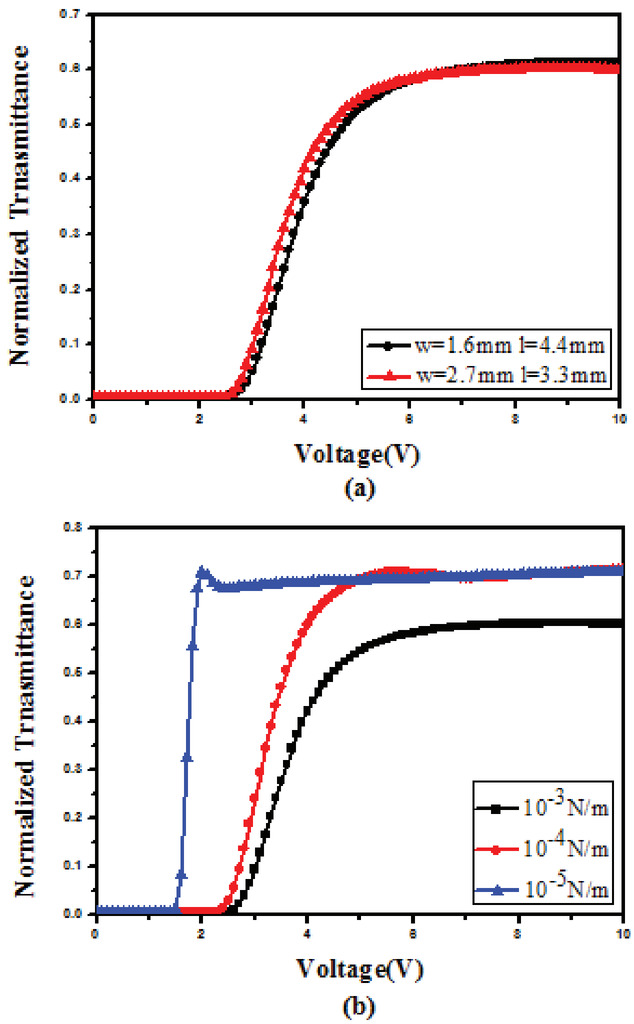

Figure 2. The voltage vs. normalized transmittance curve (a) according to size of pixel electrode (b) according to polar anchoring energy of surface substrate (l=3.3μm).

Fig. 3(a). Based on this result, we designed the following four different cases and tested electro-optic performances. The normal 4-domain structure has a (l, w) equal to (4.4, 1.6) in μm, with $W_\theta = 10^{-3}$N/m. For 8-domain PS-VA mode, a pixel was divided into main and sub regions. In case 1, the (l, w) in μm in main and sub region were defined to be (4.4, 1.6) and (3.3, 2.7), respectively, while both W_θ and W_φ anchoring energies were 10^{-3}N/m. In case 2, different polar W_θs were defined such that its value is 10^{-4}N/m and 10^{-3}N/m in sub and main regions, respectively, while the W_φ is 10^{-3}N/m, as shown in Fig. 1(a). In case 3, the main and sub regions including anchoring energy were interchanged, as shown in Fig. 1(b). For all cases, the ratio of the main and sub region is 2:1. Fig.3 (b) shows V-T curves for all four cases. Case 1 represents about the same curve as that of 4-domain, whereas the curves related to Case 2 and 3 are shifted to lower voltage side. The threshold voltage values for Case 2 and Case 3 are 2.8V and 2.7V, which are reduced by 0.2V and 0.3V compared to 4-domain, respectively. In addition, the transmittance is also increased for case 2 (8.07%) and case 3 (10.38%) compared to that of 4-domain owing to weaker anchoring energy region which render LC direction more to 45° with respect crossed polarizer transmittance. Fig. 4 shows how the transmittance changes according to applied voltages for each case. As can be seen, case 2 and case 3 clearly exhibit the transmittance difference between two regions more than that in case 1, indicating that the difference in tilt angle in two regions is larger in case 2 and case 3 than that in case 1.

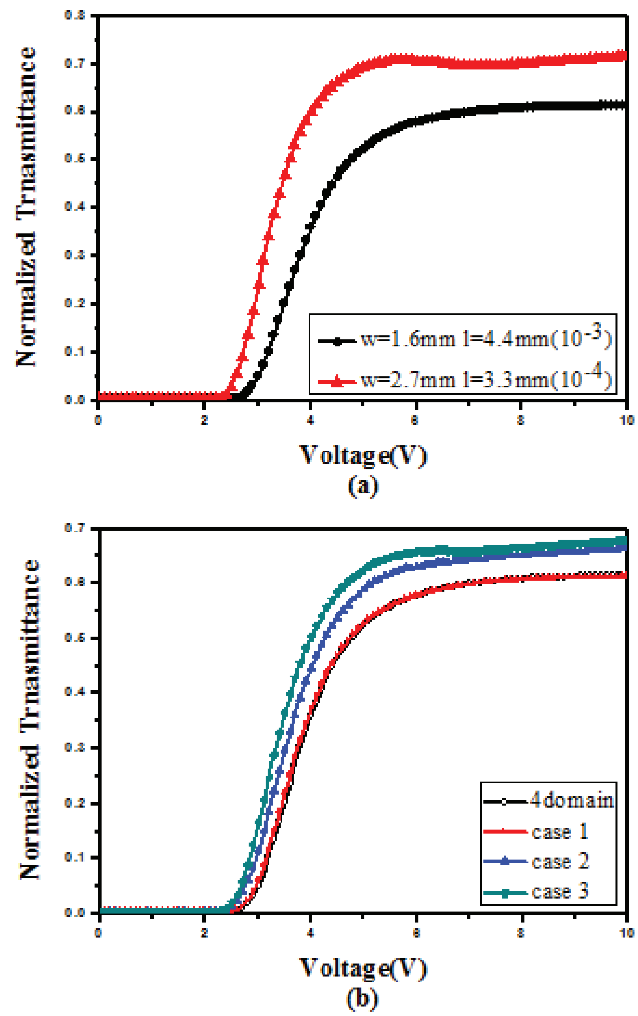

Figure 3. V-T Curve (a) Main-4.4μm and sub-3.3μm regions (b) Four cases

Figure 5 depicts the luminance change according to the gray scale levels according to viewing directions. Here, the gamma curve with $\gamma = 2.2$ at normal direction is applied. For comparison, the azimuthal angle 0° which is coincident with the polarizer axis is selected while changing a polar angle from 0° to 60°. As indicated, 4-domain, case 1 and case 3 exhibits inversion of the gamma curves according to viewing directions whereas case 2 does not show it, that is, case 2 shows the reduction in the gamma distortion. The gamma distortion index defined in the following equation [12];

$$GDI = AVG\left\langle \left| L_{i(on\text{-}axis)} - L_{i(off\text{-}axis)} \right| \right\rangle_{i=0\sim255}$$

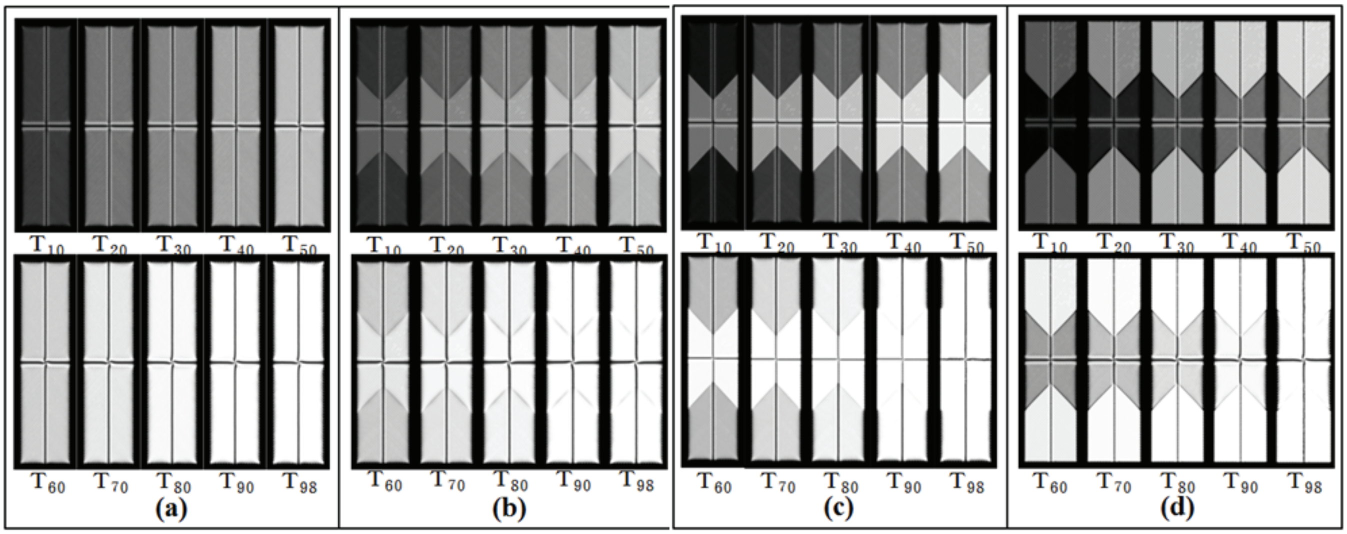

Figure 4. Transmittance in a pixel for four cases according to grey scales: (a) 4-domain, (b) case 1, (c) case 2, (d) case 3. T indicates the transmittance and the number in subscript indicates transmittance change from a dark state.

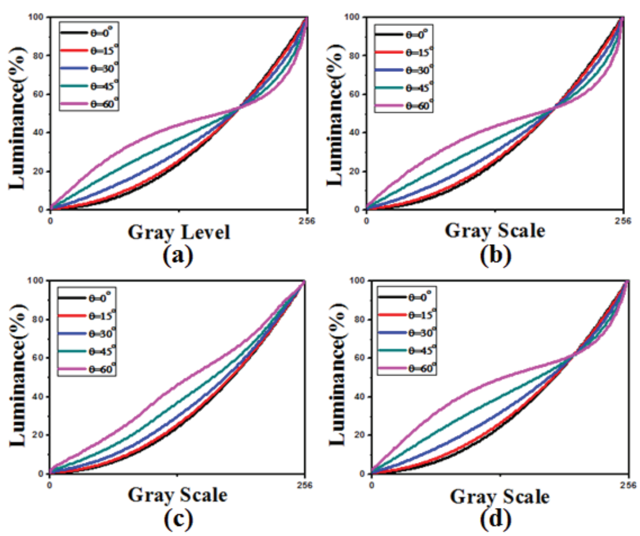

Figure 5. The gray level vs. gamma curve of polar viewing angle at azimuthal angle of 0^o: (a) 4-domain, (b) case 1, (c) case 2, (d) case 3

where $L_{i(on\text{-}axis)}$ and $L_{i(off\text{-}axis)}$ represents a brightness corresponding to i^{th} gray level luminescence at on-axis and off-axis, respectively, and the AVG< > represents the average of 0 to 255 grey levels.

From the 4-domain results, the calculated gamma distortion index (GDI) for polar angles of 60º and 30º are 14.17 and 4.25, respectively. In Case 1, the only change is in the structure of electrodes, the GDI is 4.50 for a polar angle of 30º, and 15.71 for a polar angle of 60º. In this case, GDI exhibits more reduction than that of the 4 domain. Case 2, the GDI was reduced to 3.28 (23% improvement compared to standard 4 domain) when a tilt angle is 30º, and reduced to 13.10 (8.1% with compare to standard 4 domain) for a tilt angle 60º. In Case 3 also GDI was reduced to 4.08 and 13.84 for 30º and 60º, respectively. It was conformed that the case 2 has a huge gamma distortion reduction.

3. Conclusion

We proposed 8-domain structure for PS-VA by controlling anchoring energies (which could be a surface pretilt angle) and pixel structure at each domain. This new structure is having an advantage of cost effective and no additional process was required for electrode design while keeping a high contrast ratio at normal direction. As a result, we would expect to be able to make a liquid crystal device having a wide viewing angle and the high optical efficiency through the proposed new method.

4. Acknowledgements

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