Multi-Domain In-Plane Switching Liquid Crystal Cell using the Photo Alignment Method

Byung-June Mun, Ki-Woong Park, and Gi-Dong Lee

Department of Electronics Engineering, Dong-A University, Busan 604-714, South Korea

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ABSTRACT

We proposed the photo-aligned multi-domain In-plane switching (IPS) liquid crystal (LC) mode by double exposing the ultra-violet (UV) light to achieve both of the high transmittance and wide-viewing properties. Also, the optical performance of the proposed IPS LC cell is demonstrated from the experiments in this paper.

1. INTRODUCTION

In general, in-plane switching (IPS) liquid crystal (LC) mode is widely used for display applications such as a mobiles, notebooks, monitors and TVs because of its high transmittance and wide-viewing angle properties [1-3]. In spite of the good viewing angle properties in the on-axis, the distortion of the viewing angle could be shown in the off-axis because of the single domain effect of a basic IPS LC cell. To improve the optical distortion, the many of the previous papers proposed the optical structure by using the anisotropy films such as *A*-plate and *C*-plate [4, 5]. In this research, the light leakage of the IPS LC cell could be effectively compensated in both on-axis and off-axis, so that the excellent viewing angle and iso-contrast ratio properties were obtained. However, optical compensation films are difficult to control the birefringence properties, and have also high cost for fabrication. In the different ways, a super IPS (S-IPS) mode [6] which is designed as zigzag electrode structure could be proposed for improving the viewing angle properties. The zigzag electrode of a S-IPS cell makes the multi-domain area in the bright state so that the wide-viewing angle properties can be performed by optical anisotropy. On the contrary, it can diminish the aperture ratio in the active area and also generate several disclinations around the edge of the electrodes and boundary of the multi-domain area due to the zigzag electrode pattern. Therefore, these distortions lead poor brightness to the extent that the optical transmittance of the S-IPS cell is somewhat lower than that of the conventional IPS cell.

In this paper, we proposed the photo-aligned multi-domain IPS LC cell, which applies the basic stripe electrodes, to improve both of the transmittance and viewing angle properties. The establishment of multi-domain area is performed by double-exposed ultra-violet (UV) alignment method to the up/down domain of active area. From the calculation and experiments, we confirmed that the proposed IPS mode simultaneously provides an excellent multi-domain effect and high transmittance.

2. THE OPTIMIZED OPTICAL PRINCIPLE OF THE PROPOSED IPS LC CELL

Figure 1(a) and 1(b) show the electro-optical principle of the LC molecules on each domain of the proposed IPS LC cell along the applied electric field. In the Fig. 1(a), we set the initial LC molecules to the slightly tilted angle $\pm\alpha$ from the transmission axis of the polarizer on the upper/bottom domain area because of the multi-domain structure on the strip electrode structure in the voltage on state. When the voltage was applied between the electrodes, LC molecules placed on the upper/down domain area were reoriented at ±45° angles which is the maximum effective retardation angle in the homogeneous LC cell. Consequently, the proposed IPS cell shows the multi-domain effect on the stripe electrode structure in the voltage on state in the Fig. 1(b).

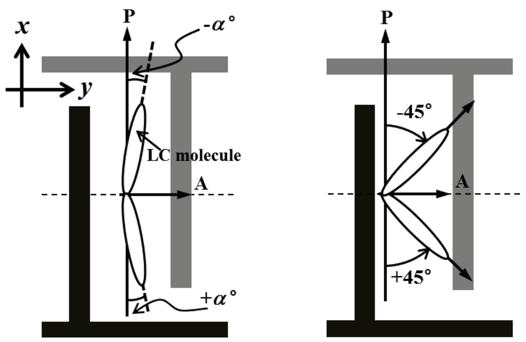

Fig. 1(a) Fig. 1(b)

Fig. 1. The orientation of the LC molecules for the upper/down domain area of the proposed IPS LC cell (a) in the dark state and (b) in the bright state

To satisfy these optical performances of the proposed LC cell, however; we should decide the angle α which is able to provide both the good dark level and the sufficient multi-domain effect. Therefore, we first calculated the optical transmittance as a function of the angle α as follow equation [7, 8]:

$$T = \sin^2(2\alpha)\sin^2(\pi d \Delta n_{eff} / \lambda) \qquad (1)$$

where, d is the cell thickness, Δn_{eff} is the effective birefringence of the LC layer, and λ is the wavelength of the incident light. As calculated results of the optical transmittance from the equation (1), we confirmed that the light leakage in the dark mode appears less than 0.1% compared to the case that the transmission axis of the polarizer is coincident to the optical axis of the LC molecules if the angle α is 0.5°. Therefore, if the alignment angle α for the multi-domain effect was induced within 0.5°, we can achieve both of the high aperture ratio and the high transmittance with less than 0.1% light loss in the dark state of a proposed IPS LC cell. However, we checked that ±0.4° of the angle α does not show the multi-domain effect of the proposed IPS cell in the bright mode from the experiments. Consequently, we optimized the minimum angle for achieving the multi-domain effect in the bright state to ±0.5°.

3. EXPERIMENTS AND RESULTS

In order to demonstrate the optical performance of the proposed IPS LC cell, we fabricated the IPS sample cell with the photo-aligned multi-domain structure. Figure 2 illustrates the cell structure for fabricating the proposed IPS cell.

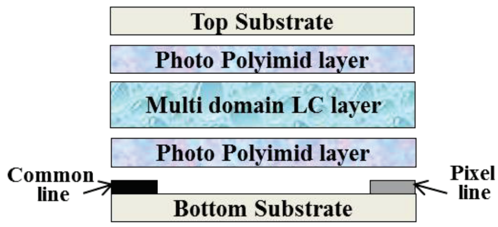

Fig. 2. The cross-sectional view of the cell structure for fabricating the proposed IPS LC cell

In case of the basic IPS cell as shown in Fig. 2, the top substrate has no indium tin oxide (ITO) electrode layer and the bottom substrate has applied the stripe patterned electrode which consists of the pixel line and the common line for improving the aperture ratio. Here, the electrode width of both the pixel and common line is 10μm and the interval between two electrodes is 40μm, respectively. On each substrate, we spin-coated the photo-alignment layer which can induce the chemical reaction of the photo degradation in order to provide the multi-domain effect of the active area by using the linearly polarized UV light.

Figure 3 shows the simple fabrication process for establishing the multi-domain area of a proposed IPS sample cell. Firstly, we prepared two substrates. Especially, the stripe patterned ITO electrode of a bottom substrate could be formed by the photo-lithography process in Fig. 3(a). Then, the photo polyimide material (PIA-PA57-08X, JNC Co.) was respectively spin-coated on two prepared substrates and then, the photo-polyimidization process was performed by hard-baking at 230°C for 1.5 hours as shown in Fig. 3(b).

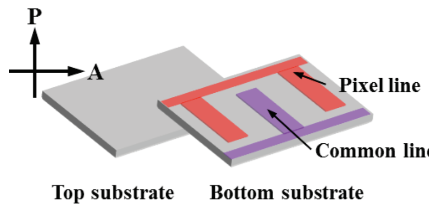

Fig. 3(a)

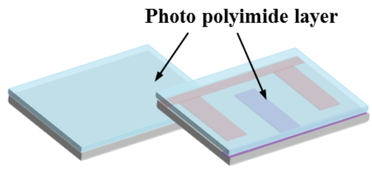

Fig. 3(b)

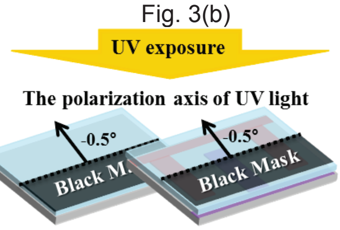

Fig. 3(c)

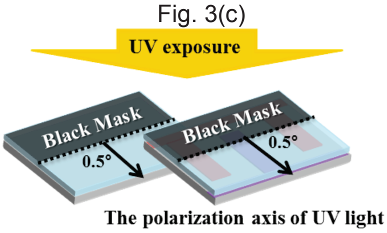

Fig. 3(d)

Fig. 3. The schematic diagram of the simple fabrication process for achieving the multi-domain effect in a proposed IPS LC cell: (a) the preparation of the top and bottom substrate, (b) the spin-coating of the photo polyimide material, (c) the exposed UV alignment in the upper domain area, and (d) the exposed UV alignment in the down domain area.

Next, we performed the double-exposed UV alignment on upper/down domain by using the black mask in order to orient LC molecules to optimized angle ±0.5° at each domain area in Fig. 3(c) and 3(d). The intensity of the UV light source was 21mW/cm^2 at a wavelength of 365nm. While exposing the UV light to the upper/down domain, the black mask should be shifted on each domain area to block the opposite domain area from the UV light. In this process, it is very important to align the exact UV alignment direction of the top and bottom substrate when assembling two substrates because of the deterioration of the multi-domain effect and the light leakage in the dark state when exposing the UV light. For this reason, we applied the alignment key, which can indicate the position between the upper and down domain area on top and bottom substrate. Finally, the LC (MLC-7037, $\Delta\varepsilon$ = 5, and Δn = 0.1144, Merck) was injected into the LC layer with the cell gap of 3μm, followed by the annealing of the sample cell at 100°C due to the enhancement of the LC ordering.

Figure 4 shows the microscopic images of a sample IPS cell under crossed polarizers. In the voltage off state in Fig. 4(a), we observed that the light leakage of the proposed IPS cell almost not occur in the active area of each domain because of the optimized UV alignment angles for the multi-domain effect. We also checked the multi-domain effect of the sample IPS cell at 15V after rotating the sample to 20° from the polarization axis of the polarizer in Fig. 4(b) to show the difference of the transmittance of upper/down domain. As expected, optical axes O_1 and O_2 of upper/down domain area are closed to 0° and 45°, respectively, so that we could observe the different states which are bright state in the upper domain area and slight dark state in the down domain area in a simple cell. Finally, we could confirm that both of the good dark level and the multi-domain effect could be performed in the proposed IPS LC cell.

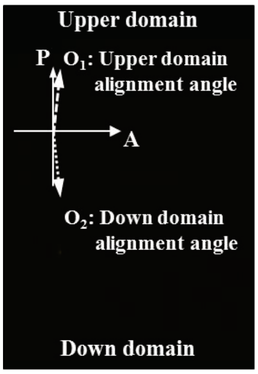

Fig. 4(a)

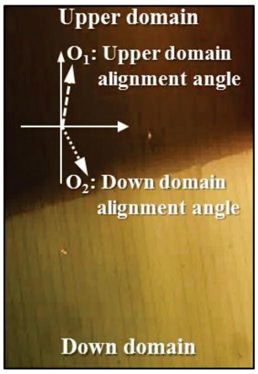

Fig. 4(b)

Fig. 4. The optical microscopic images of the fabricated IPS sample cell under crossed polarizers if the rotation angle of the cell is (a) 0° and (b) 20° from the optical axis of the polarizer.

Figure 5 shows a comparison of the calculated optical transmittance in a basic IPS LC cell, a conventional S-IPS LC cell and a proposed IPS LC cell. The inset boxes in the Fig. 5 show the optical microscopic photographs of the measured optical intensity of the simple cell under crossed polarizer as a function of the applied voltage. In case of the proposed IPS cell, we could see that the transmittance graph is almost agreed with that of the basic IPS mode although the maximum transmittance was slightly reduced compared to that of the basic IPS mode because of the small disclination line between the upper/down domain areas as shown in the inset box at 26V. Moreover, we observed the fact that the optical transmittance of the proposed IPS cell was 15% higher than in the conventional S-IPS mode. From the results, we can expect both a high transmittance and an excellent viewing angle properties compared to the conventional S-IPS LC cell.

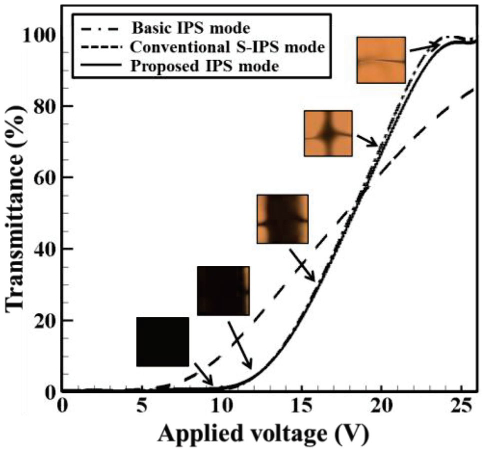

Fig. 5. The comparison of the calculated voltage-transmittance (V-T) curve in a basic IPS mode, a conventional S-IPS mode and a proposed IPS mode including the measured optical intensity of the LC cell.

4. Conclusion

In conclusion, we proposed the IPS mode with a stripe electrode that can show multi-domain effect using the double-exposed UV alignment method to the upper/down domain of the active area. We optimized the initial UV exposure angles for the upper/down domain area to angle 0.5°, which scarcely affected to the dark state. Experiments for demonstrating the optical performances of the proposed IPS LC cell was performed so that we could confirm that both excellent optical transmittance and the wide-viewing properties in bright state could be achieved in the proposed IPS cell with high aperture ratio. Finally, we compared the transmittance of three IPS LC cell, which consists of a basic IPS cell, a conventional S-IPS cell and a proposed IPS cell. As results, we achieved that the light transmittance of the proposed IPS LC cell was more than 15% better than that of the conventional S-IPS LC cell without any optical loss of the dark level and the viewing angle properties.

5. ACKNOWLEDGEMENT

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