3-D FEM Study on the Optical Characteristics of S-IPS Mode

Seung Su Yang, Soon Yeol Park and Teayoung Won
Department of Electrical Engineering, College of IT Engineering, Inha University
253 Yong Hyun Dong, Nam Ku, Incheon, Korea
TEL:82-32-875-7436, e-mail: yss@hsel.inha.ac.kr.

Keywords : in-plane switching, super-IPS, liquid crystal display, numerical simulation

Abstract

In this paper, we propose a novel electrode structure for superb transmittance in super in-plane switching (S-IPS) mode while keeping the features of the conventional S-IPS mode such as the capability of initial LC alignment. The optimization of the electrode made it possible to enhance the light transmittance approximately by 14 % in comparison to the conventional S- IPS cell.

1. Introduction

A great deal of research efforts are being made for developing a high-performance liquid crystal display (LCD) such as high light transmittance, fast response, high contrast ratio (CR), color gamut, and wide viewing angle. A variety of operational mode has been proposed in an effort to satisfy the stringent optical and electrical requirement in the display market. Among many technical approaches, in-plane switching (IPS) mode is considered to have a unique feature of wide viewing-angle characteristics due to its inherent lateral electric field.

Typical IPS cell comprises a couple of electrodes implemented on the same substrate in such a way that the induced in-plane electric field twists the LC directors for light transmission through the crossed polarizer [1, 2]. Furthermore, the Super In-Plane Switching (S-IPS) technology, which stems from the original IPS mode, employs two-domains for super wide viewing angle and less color shift. However, the S-IPS mode suffers from a shortcoming in that light transmittance is poor due to the presence of a strong vertical electric field across the surface of the electrode, which causes the LC directors in these regions to tilt rather than to twist. Consequently, the light transmittance above the electrode is seriously deteriorated [3].

Therefore, we have undertaken a numerical study of optimizing the cell architecture in an effort to overcome the technical problem of the traditional S-IPS cell. The research goal of this paper is to devise cell architecture for S-IPS mode cell which resolves the issue of poor light transmittance while keeping the inherent features of the S-IPS mode such as the anchoring of the initial LC alignment.

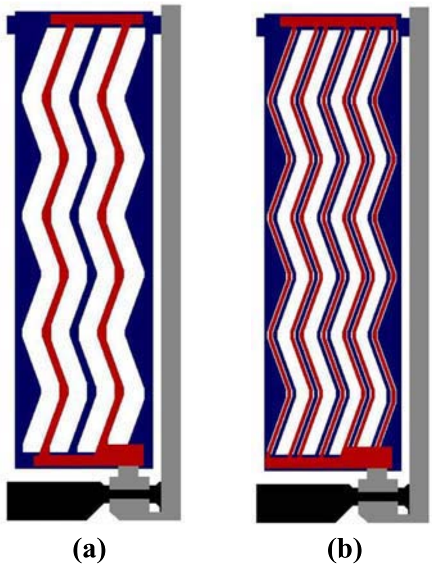


Fig.1. Liquid crystal display cell configuration: (a) conventional S-IPS cell and (b) proposed high transmittance S-IPS cell (Case 2)

2. Cell Configuration and Parameters

Figures 1(a) and 1(b) are schematic diagrams illustrating the cell layouts of a prior-art S-IPS mode and our high-transmittance S-IPS mode in this study, respectively. The design issue was focused on achieving a superior light transmittance while keeping the inherent features of the traditional S-IPS mode. As aforementioned, the prior-art S-IPS cell has a shortcoming in that strong vertical electric fields are produced across the surface of the electrode, which causes the LC directors to tilt rather than to twist.

Consequently, the light transmittance above the electrodes is remarkably reduced.

By noting the above-mentioned problem of the conventional S-IPS cell structure, we devised a novel electrode structure wherein each common electrode is replaced by a group of electrodes comprising a pixel electrode surrounded by two common electrodes. Furthermore, each pixel electrode is replaced by another group of electrodes comprising one common electrode which is neighbored by two pixel electrodes. The proposed architecture makes it possible to produce fringe fields as well as the horizontal field components within each group of electrode by keeping a strong horizontal electric field exist between the groups of electrode. Consequently, the LC directors throughout the entire cell can be rotated to achieve a high light transmittance [4].

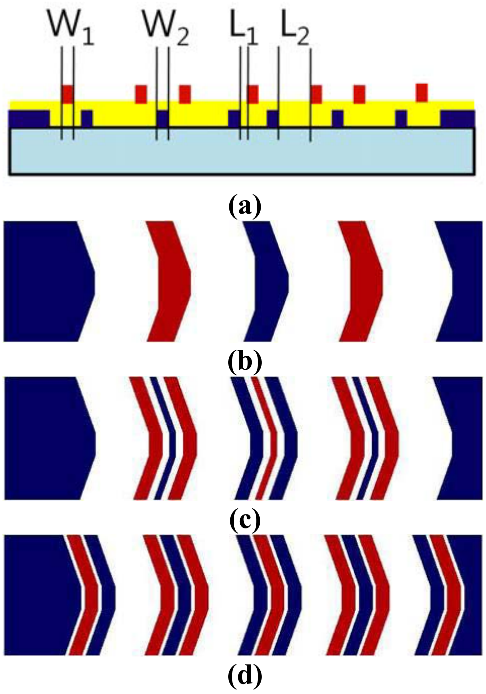


Fig.2. Electrode structure illustrating the proposed high transmittance Super-IPS LC Cell. (a) Cross-section view, (b) Case 1, (c) Case 2, (d) Case 3

Figure 2(a) is a plot illustrating the geometrical design parameters and dimension for electrodes in the S-IPS cell. In order to optimize the optical characteristics of the proposed architecture for S-IPS, we investigated three trial cases with different geometrical dimension in pixel and common electrodes (Case 1: W1 ≠ W2; Case 2: W1 = W2; Case 3: L1 = 0). Here, W1 is the width of the pixel electrode and W2 is the width of the common electrode. In addition, L1 is the distance between the pixel electrode and the common electrode while L2 is the distance between two electrode groups. Figures 2(b), 2(c), and 2(d) are schematic diagrams illustrating the layout for each trial cases: Case 1, Case 2, and Case 3, respectively.

We performed numerical simulations for the three trial cases with the material data as the following: a positive Δε LC materials (MLC-6692 from Merck: dielectric anisotropy Δε=10.3, K11=9.2 pN, K22=6.1 pN, K33=14.6 pN, no=1.4771 and ne=1.5621). The cell gap is assumed to be 4 ㎛, and the size of the LC cell is 88 width × 264 length. Therefore, we also fixed simulation region as 88 × 264 ㎛ for each case. The conventional S-IPS cell was also simulated for the comparison.

For our numerical analysis of molecular behavior of liquid crystals, we employed three-dimensional finite element method (3D-FEM) numerical solver software, 'TechWiz LCD', the numerical engine is based on the solution of Ericksen-Leslie equations and 2 × 2 Jones matrix scheme for the optical analysis [5, 6].

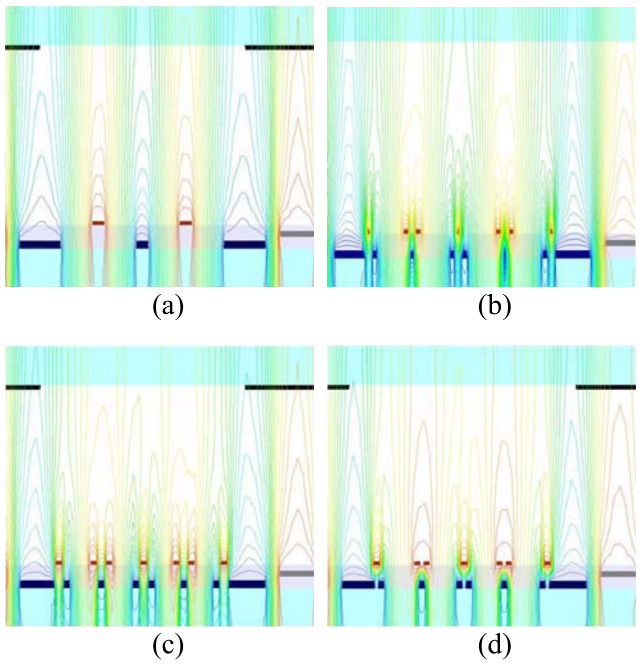
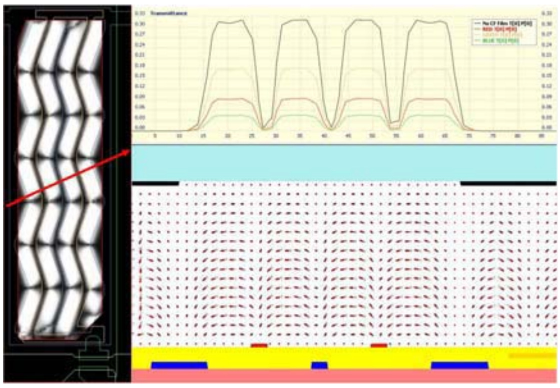


Fig. 3. Potential distribution in different common and pixel electrode design. (a) Conventional Super-IPS LC cell , (b) Case 1, (c) Case 2, (3) Case 3.

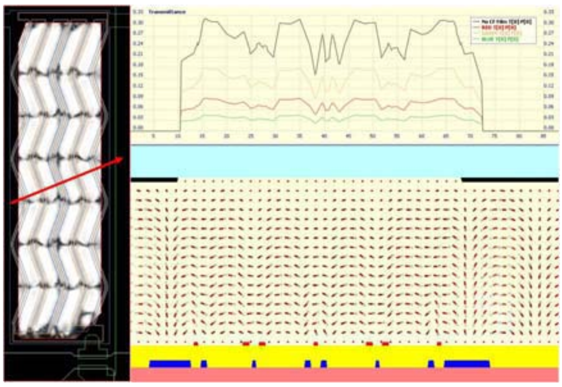
3. Simulation Results and Discussion

Figures 3(a), 3(b), 3(c), and 3(d) are plots illustrating the calculated potential contours for prior-art S-IPS, Case 1, Case 2, and Case 3 of this study, respectively. Referring to Figure 3(a), we can notice that there exist substantial horizontal electric fields between the pixel electrode and the common electrode, and a strong vertical electric field also exist above the surface of the electrode. Consequently, the LC directors will mainly tilt rather than twist above the electrode surfaces, resulting in a low transmittance there.

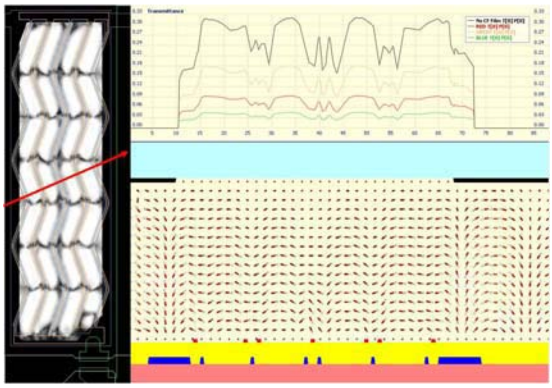
This simulation results motivated us to invent new electrode architecture which enhances the light transmittance in these regions. With the proposed electrode configuration, fringe fields with the horizontal field components are generated within each electrode group and substantial horizontal electric fields flourish between the electrode groups, as shown in Figure 3(b), (c), (d).



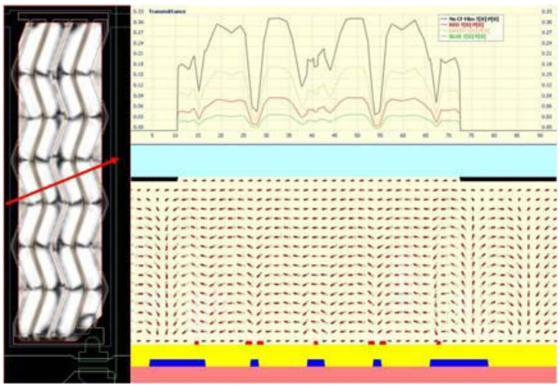
(a)



(b)



(c)



(d)

Fig. 4. Simulated director distribution and Transmittance curves with respect to electrode position: (a) Conventional Super-IPS cell, (b) Case 1, (c) Case 2, (d) Case 3

Figures 4(a), 4(b), 4(c), and 4(d) are schematic diagram which illustrate the calculated director distribution (right below), light transmittance curves as a function of electrode position (right above), and light transmission at a cross section as designated in the figures, for the conventional S-IPS cell, Case 1, Case 2, and Case 3, respectively. Referring to Figures 4(a), 4(b), 4(c), and 4(d), we can notice that the light transmittance of three trial cases (Case 1, Case 2, and Case 3) is even higher than that of the conventional S-IPS in the regions above electrode surfaces. As far as the light transmittance is concerned, Case 2 (Figure 4(c)) exhibits the highest value due to the fact that the electrode groups can switch the LC directors much more efficiently [7].

In Figure is shown the calculated voltage-transmittance (V-T) characteristics. Referring to Figure 5, we can find that total amount of transmittance of the proposed S-IPS cell (Case 1) is found to be approximately 14% higher than that of the conventional S-IPS.

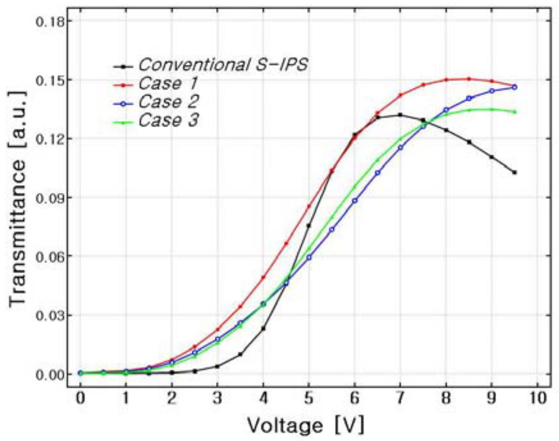
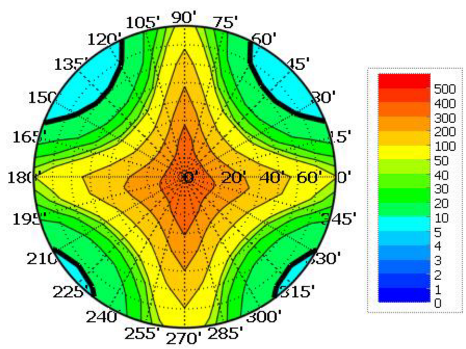
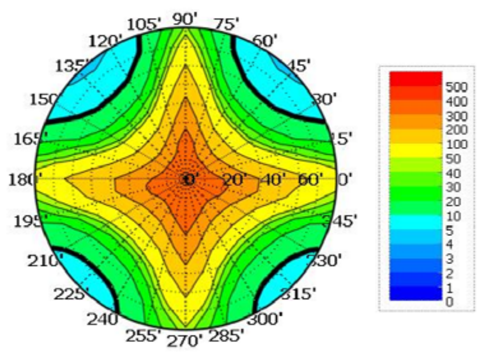


Fig. 5. Voltage-dependent light transmittance curves for the conventional Super-IPS cell and proposed Super- IPS cells.



(a)



(b)

Fig.6. ISO-Contrast plots for (a) the S-IPS cell and (b) the proposed IPS cell.

Figures 6(a) and 6(b) are plots illustrating the calculated ISO-contrast ratio (ISO-CR) contour of the prior art and Case 1, respectively. We compared the iso-contrast contours of S-IPS and proposed S-IPS mode cell under their respective maximum transmittance voltages at a wavelength λ=589 nm. The black line in each polar chart represents the contrast ratio wherein the value of CR is 10. Our novel S-IPS mode (Case 1) exhibits slightly wider viewing angle than the conventional S-IPS.

4. Summary

We propose a new electrode design S-IPS cell which does not lose the merits of conventional S-IPS mode while exhibiting a superior light transmittance. We analyzed and compared electro-optical characteristics such as voltage-transmittance curve and iso-contrast by 3D-FEM simulation. Compared to the prior-art S-IPS mode, the proposed S-IPS cell architecture exhibits 14% increase in the light transmittance and better viewing angle performance.

5. Acknowledgment

This research was supported by the Ministry of Knowledge Economy, Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute of Information Technology Advancement) (IITA-2008-C109008010030).

6. References

1. R.A.Soref, J. Appl. Phys., vol.45, pp. 5466–5468, (1974).
2. M.Ohe and K. Kondo, Appl. Phys. Lett., vol. 67, pp. 3895–3897, (1995.)
3. M.Schadt and W. Helfrich, Appl. Phys. Lett., vol. 18, pp. 127–128, (1971).
4. Z. Ge, Journal of Display Technology, vol. 2, pp. 114-120 , (2006).
5. H.J. Youn, C.S. Lee, M.S. Jung, S.H. Yoon, T. Won, IMID'05 Digest, pp. 515-518, (2005).
6. S.H. Yoon, S.I. Yoon, C.S. Lee, H.J. Yoon, M.W. Choi, J.W. Kim, T. Won, IDW'03 Proceedings, pp. 49-52, (2003).
7. W.J. Shin, S.Y. Cho, J. B. Lee, H.Y. Yoon, S.H. Yoon, T. Won, AM-FPD'07 Digest, pp. 41-44, (2007).