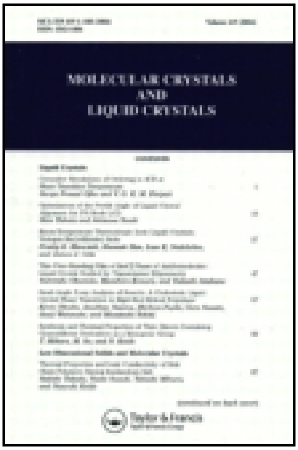

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Numerical Optimization of Electrode Structure for Super-IPS LC Cell Operation

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In this paper, we propose a novel super in-plane switching (S-IPS) architecture wherein each common electrode is replaced by a group of electrodes comprising a pixel electrode surrounded by two common electrodes and each pixel electrode is replaced by another group of electrodes comprising one common electrode which is adjacent to the pixel electrodes. The reorientation properties of the LC directors is observed in the proposed cell architecture and the existence of the horizontal as well as the fringe field in the cell regions enhances the light transmittance approximately by 14% over the conventional super IPS cell, while keeping the inherent feature of wide-viewing angle.

Keywords: 3D FEM simulation; in-plane switching; liquid crystal display; numerical simulation; Super-IPS mode

INTRODUCTION

A variety of operational modes for implementing liquid crystal (LC) display have been proposed in order to satisfy the stringent optical and electrical requirement such as sufficient light transmittance, fast response, high contrast ratio (CR), color gamut, and wide viewing angle. Among many technical approaches, in-plane switching (IPS) mode is considered to have an acceptable feature of wide viewing-angle characteristics due to its inherent lateral electric field.

Typical IPS cell comprises a couple of electrodes on the same substrate in such a way that the induced in-plane electric field twists the LC molecules for light transmission through the crossed polarizer [1,2]. Furthermore, the Super In-Plane Switching (S-IPS) technology,

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which stems from the original IPS mode, employs two-domains for super wide viewing angle and less color shift. However, the S-IPS mode needs to find a way to achieve a further improvement in the light transmittance since the presence of a strong vertical electric field across the surface of the electrode causes the LC directors to tilt rather than twist, which deteriorates the light transmittance above the electrode [3].

Therefore, we have undertaken a study for optimizing the cell architecture in order 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.

CELL CONFIGURATION AND SIMULATION PARAMETERS

Figures 1(a) and (b) are schematic diagrams illustrating the cell layouts of a prior-art S-IPS mode and the proposed high-transmittance

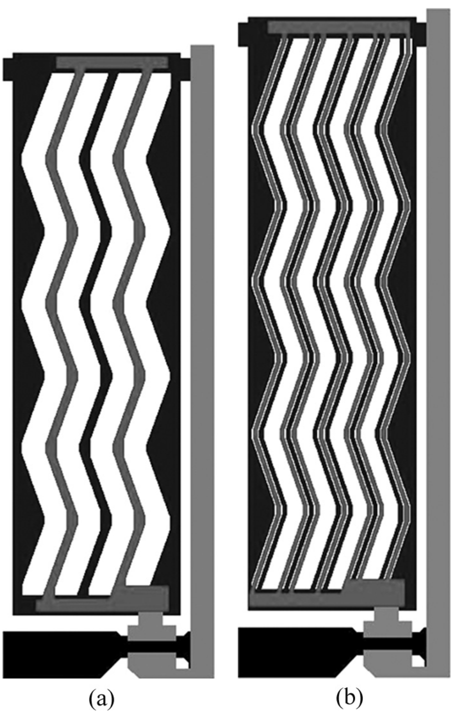


FIGURE 1 Liquid crystal display cell configuration: (a) conventional S-IPS cell and (b) proposed high transmittance S-IPS cell (Case 2).

S-IPS mode under this work, 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 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 a fringe field as well as a horizontal field within each group of the 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].

Figure 2(a) is a plot illustrating the geometrical design parameters and dimension for the electrodes in the proposed 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 the pixel and common electrodes (Case 1: $W1 \neq W2$; 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)–(d) are schematic diagrams illustrating the layout for each trial cases: Case 1, Case 2, and Case 3, respectively.

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

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

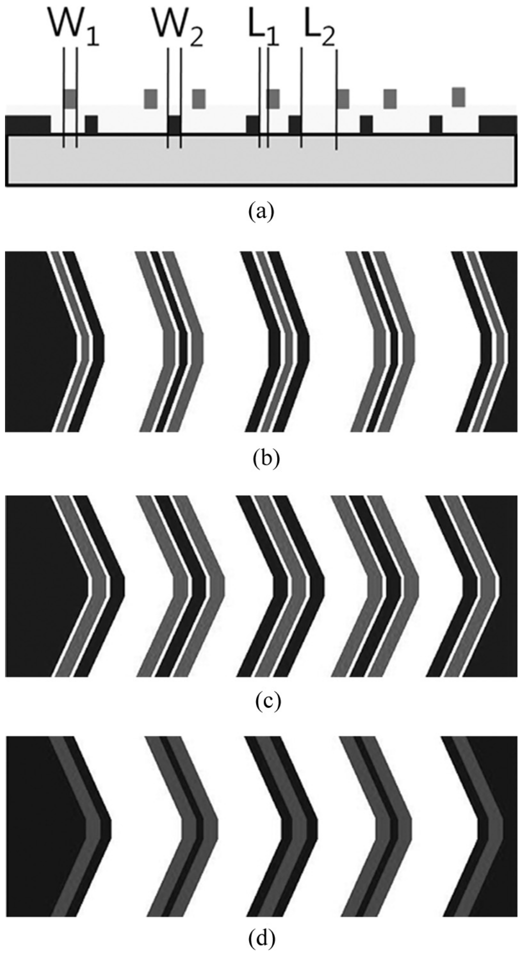


FIGURE 2 Electrode structure illustrating the proposed high transmittance Super-IPS LC Cell. (a) Cross-section view of Case 2, (b) Case 1, (c) Case 2, and (d) Case 3.

SIMULATION RESULTS AND DISCUSSION

Figures 3(a)–(d) are plots illustrating the calculated potential contours for the 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

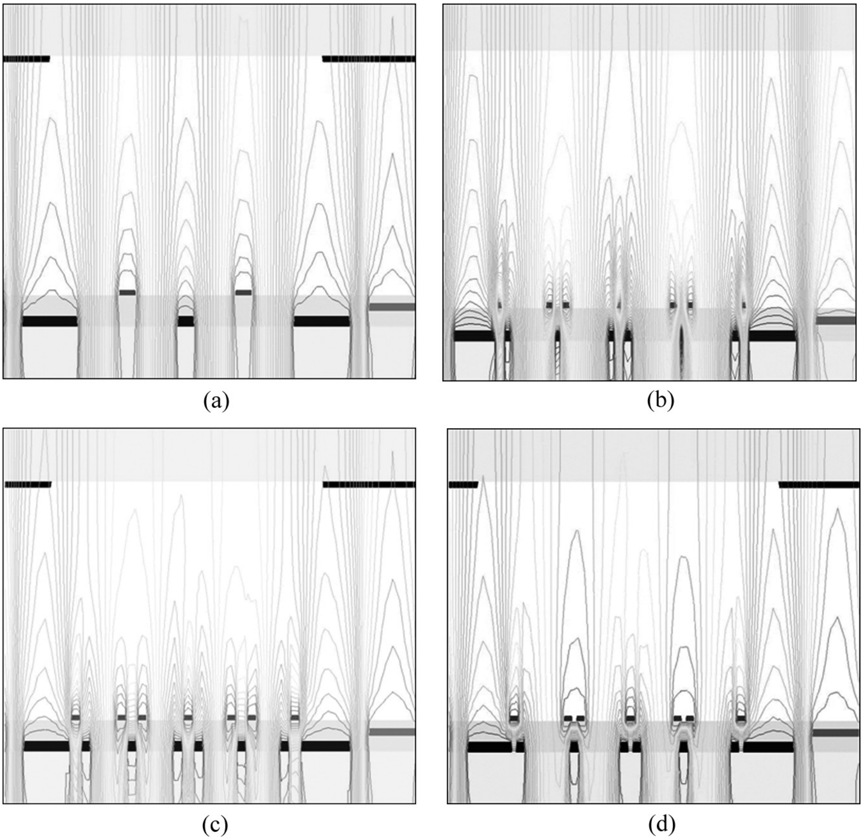


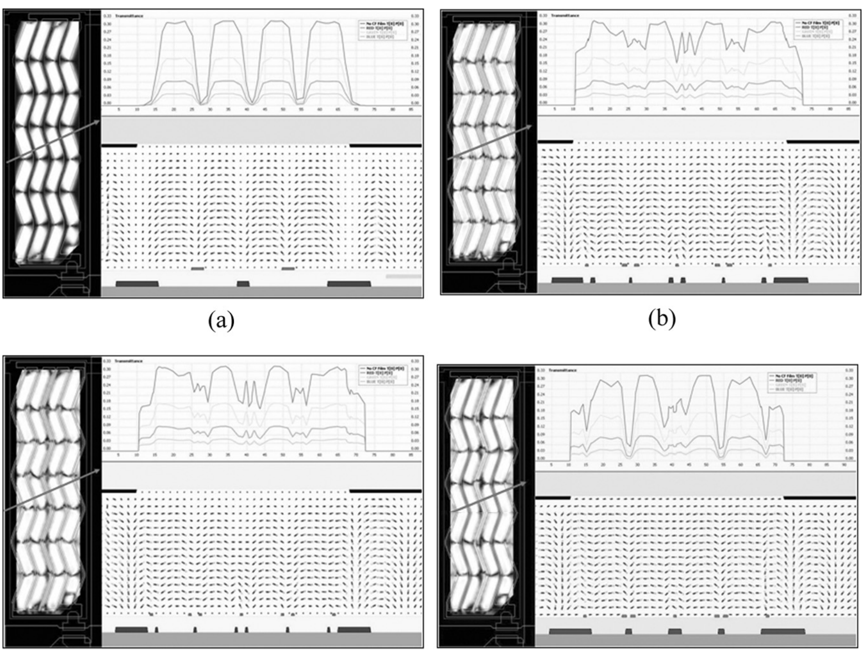
FIGURE 3 Potential distribution in different common and pixel electrode design. (a) Conventional Super-IPS LC cell, (b) Case 1, (c) Case 2, and (d) Case 3.

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, the 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)–(d).

Figures 4(a)–(d) are schematic diagram which illustrate the calculated director distribution (right below), the light transmittance curves as a function of the 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)–(d), we can see that the light transmittance of the 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 (Fig. 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 5 is shown the calculated voltage-transmittance (V-T) characteristics for each structure. Referring to Figure 5, we can find that a 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.

Figures 6(a) and (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



(a) (b) (c) (d)

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

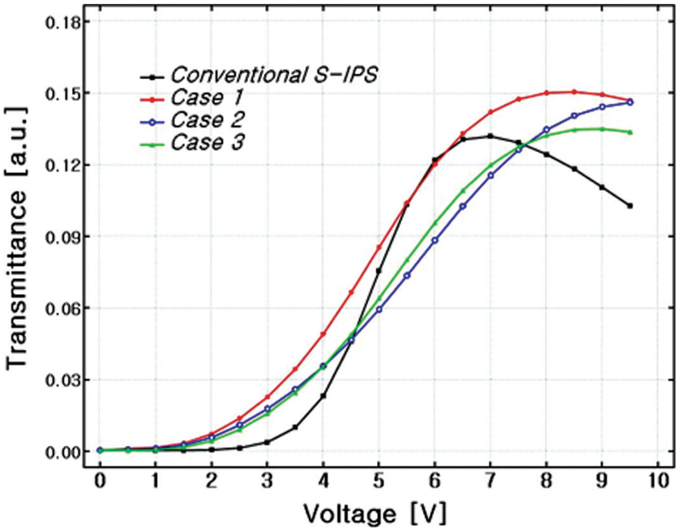


FIGURE 5 Voltage-dependent light transmittance curves for the conventional Super-IPS cell and proposed Super-IPS cells.

S-IPS mode cell under their respective maximum transmittance voltages at a wavelength $\lambda = 589\,\text{nm}$. The black line in each polar chart represents the contrast ratio wherein the value of CR is 10. The proposed S-IPS mode (Case 1) exhibits slightly wider viewing angle than the conventional S-IPS.

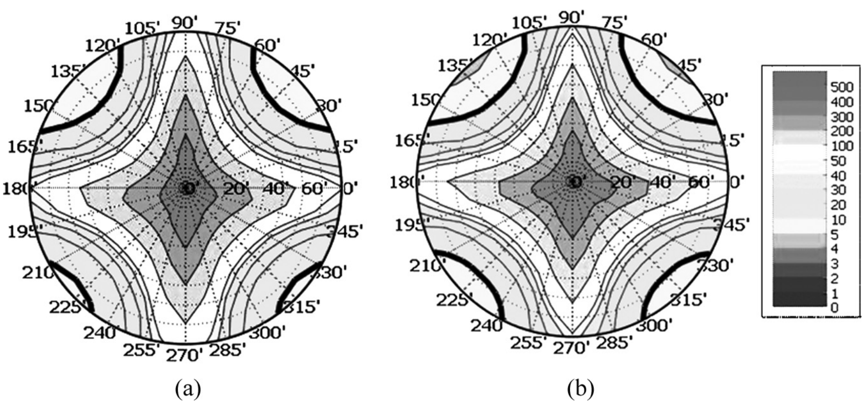


FIGURE 6 ISO-contrast plots for (a) the Super-IPS LC cell and (b) the new electrode design Super-IPS LC cell (Case 1).

CONCLUSIONS

We propose a new S-IPS cell architecture which exhibits a superior light transmittance as well as keeping the merits of the conventional S-IPS mode. We analyzed the electro-optical characteristics such as voltage-transmittance characteristics and iso-contrast properties via 3D-FEM simulation software. Compared to the prior-art S-IPS mode, the proposed S-IPS cell architecture exhibits 14% increase in the light transmittance with better viewing angle performance.

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