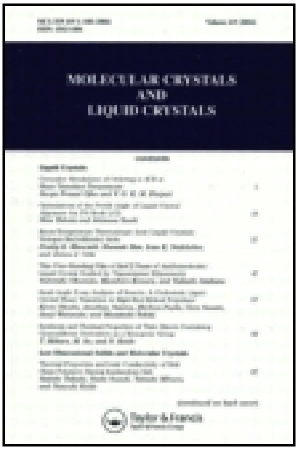

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Novel Electrode Design for High Transmittance In-Plane Switching (HT-IPS) LC Cell

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This paper proposes a novel hexagonal electrode structure for optimal operation of the in-plane switching (IPS) mode liquid crystal cell. The proposed electrode architecture was designed in an effort to ensure the enhanced light transmittance and wider viewing angle characteristics as well as reduced color shift. We looked into the dynamic response of LC molecules and the consequent light transmission behavior under the electric field with a three-dimensional finite element method simulator. Our numerical study indicate that the proposed IPS cell with hexagonal electrode structure exhibits a higher peak transmittance over the conventional IPS architecture such as super-in-plane switching (S-IPS) mode. Our simulation revealed that a design optimization is needed due to the increase of threshold voltage despite the increase of the peak light transmittance.

Keywords: FEM; high transmittance; in-plane switching; IPS; liquid crystal display; simulation

INTRODUCTION

Recently, a great deal of research effort has been made further to improve the display performance of the Liquid crystal displays (LCDs) such as the light transmittance, contrast ration, and viewing angle. In-plane-switching (IPS) mode is very promising due to inherent in-plane molecular response to the electric field, which helps to achieve wide-viewing angle characteristics [1]. The in-plane electric field produced in the IPS cell twists the LC directors and the light from the back light unit transmits through the crossed polarizer.

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The super in-plane-switching (S-IPS) mode cell, which is further an evolved version of the IPS family, comprises a couple of domains, one of which is for the purpose of achieving a wide viewing angle and the other of which is for the purpose of reducing the color gamut [2]. However, the traditional IPS modes inevitably suffer from the poor light transmission as well as the huge color shift problem since quite a strong vertical electric field exists over the electrode surface [3,4].

Therefore, we have undertaken a numerical study in an effort to devise a novel electrode architecture which ensures a superior light transmittance with less color shift as well as wide viewing angle characteristics. Our numerical study consists of the investigation of the molecular behavior of liquid crystals and the consequent electro-optic properties as a light-valve with finite element method (FEM) numerical software, 'TechWiz LCD', wherein the numerical engine is based on the solution of Eriksen-Leslie equations and 2×2 Jones matrix scheme for the optical analysis [5].

PROPOSED CELL STRUCTURE AND SIMULATION PARAMETERS

Figures 1(a) and 1(b) are schematic diagrams illustrating the architectures of the common and pixel electrodes for the prior-art IPS as a reference and our novel high transmittance IPS (HT-IPS) mode, respectively. We employed the traditional super IPS mode as the reference for comparison. We assumed the transparent metal (ITO) for pixel and common electrodes wherein they are separately deposited on the same substrate. The simulation window is assumed to be $70\,\mu m \times 234\,\mu m$ while the sizes of pixel electrode and common electrode for the reference S-IPS are $56\,\mu m \times 231\,\mu m$ and $88\,\mu m \times 234\,\mu m$, respectively. The sizes of the pixel electrode and common electrode for the proposed IPS architecture is $69.6\,\mu m \times 219.3\,\mu m$ and $70\,\mu m \times 222.8\,\mu m$, respectively.

Figure 1(c) is a layout which illustrates the proposed hexagonal electrode architecture for the IPS mode operation which has been thoroughly investigated and optimized in this work. The proposed IPS electrode structure has a feature in that the pixel electrode as well as the common electrode has a hexagonal shape. Furthermore, the individual hexagonal electrode is connected to each other through the main bone electrodes. The distance between the two neighboring hexagons, which is denoted as "a", has been optimized as $5\,\mu$ while the distance "b" is $16.5\,\mu m$. The hexagons are of regular shape and have a side length, which is denoted as "c", of $3\,\mu m$ and the tilt angle of the hexagon edge, which is denoted as "θ", of 60°. The width of the main bone electrodes, which is denoted as "d", is $1.5\,\mu m$.

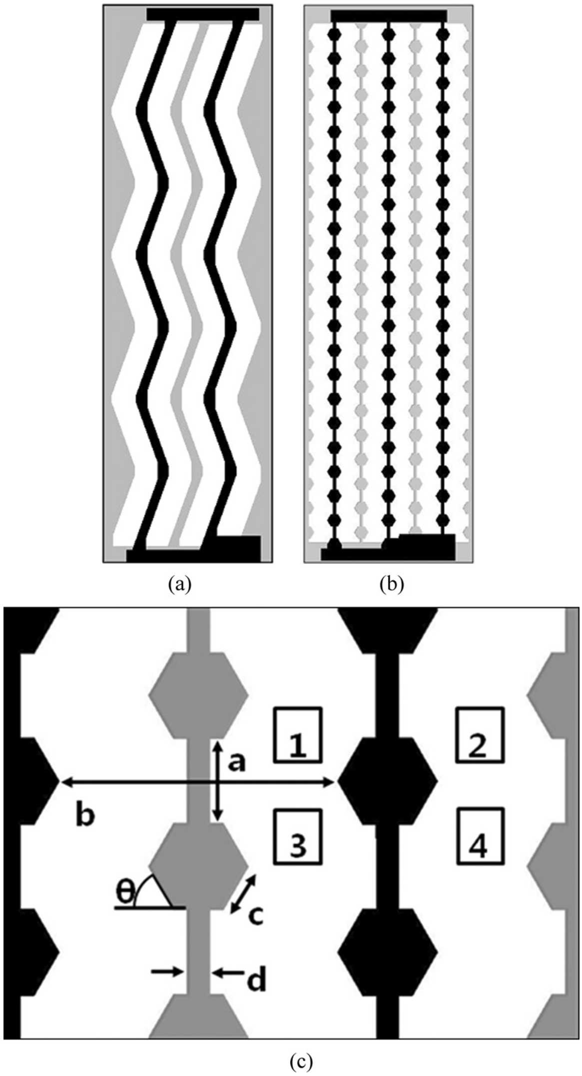

FIGURE 1 (a) Electrode layout of the conventional S-IPS cell. (b) Electrode layout of the proposed IPS mode cell. (c) Illustration of proposed electrode structure in detail.

Table 1 illustrates the simulation condition which has been employed in this simulation study. We assumed the common electrode is tied to the ground potential. As an LC material, a positive $\Delta\varepsilon$ LC

TABLE 1 Parameters Used in the Simulation Cells

LC	MLC-6692
Rubbing angle	90
Pre-tilt angle	2
Cell gap	4.4 μm
a	11.2 μm
b	16.5 μm
c	3 μm
θ	60°
Simulation size	70 μm × 234.1 μm

material MLC-6692 with K11 = 9.2 pN, K22 = 6.1 pN, K33 = 14.6 pN, $\Delta\varepsilon = 10.3$, no = 1.4771 and ne = 1.5621 at $\lambda = 589$ nm is used, wherein the cell gap is 4.4 μm and pre-tilt angle is 2° and the initial azimuthal angle (i.e., the rubbing angle) is 90°. When there is no voltage applied, the incident light is completely blocked by the cross polarizer, which results in a normally black state. When the applied voltage exceeds the threshold, the transversal electric fields are created and the electric field lines are in the parabolic form in the whole display area.

RESULT AND DISCUSSION

Figure 2 is a plot which illustrates the electric potential contours and the LC director distributions of our novel IPS cell. Referring to Figure 2, we can see the orientation of the director as well as the potential distribution at the middle of the liquid crystal layer. Figures 2(a), 2(b) and 2(c) provide the director distributions at a xy-plane under the voltages of 5 V, 6 V and 7 V, respectively. In Figures 2(a), 2(b), and 2(c), we should note that the background color indicates the potential distribution. The rotation of the cylinder symbols indicates the angle of local twist while the length of the symbols indicates the magnitude of the tilt angle. The color of the cylinder symbols indicates the direction of the twisted director.

Figure 3 is a top view of the simulated LC director distribution at the liquid crystal layer when 7 V is applied. When the applied voltage goes beyond the threshold, the LC molecules in the regions 1 and 4 tend to rotate in a clockwise direction while those in the regions 2 and 3 start to rotate in a counterclockwise direction. This counter rotation of directors in both regions is considered to be very effective for compensating the color shift [6,7].

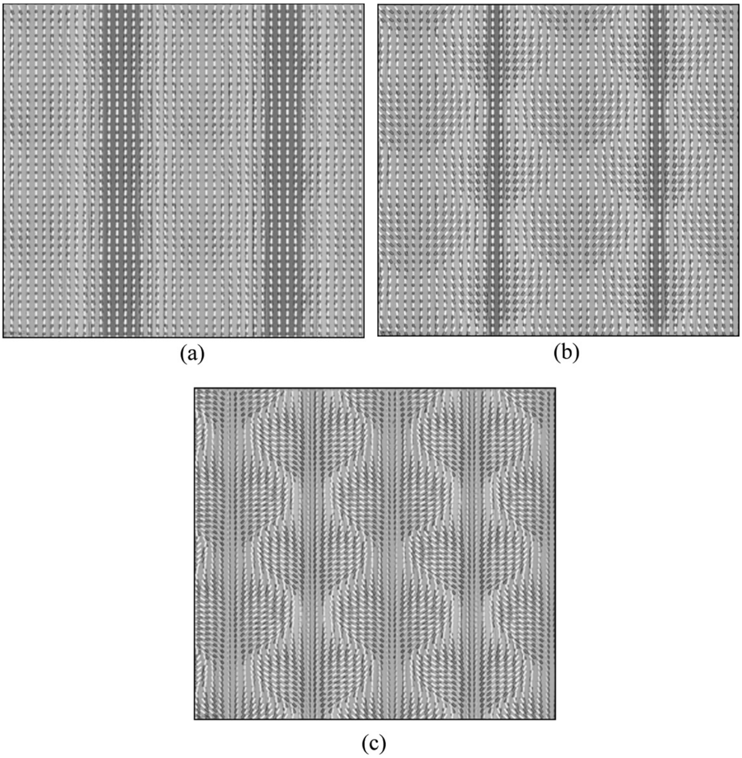

FIGURE 2 Director distribution in the middle of the liquid crystal layer, (a) 5 V, (b) 6 V, (c) 7 V.

Figure 4 is a diagram illustrating the light transmittance as a function of the applied voltage for the conventional S-IPS (lines with empty circles) and the proposed IPS mode cell (lines with filled circles). Referring to Figure 4, we can see that the peak transmittance of the proposed IPS mode cell is higher than that of the conventional S-IPS mode cell approximately by 11.9%. We also recognize that the voltage for the peak transmittance shifts to the right for the proposed structure when compared with the conventional S-IPS structure. In the meantime, the threshold voltage of the conventional S-IPS mode cell is lower than that of the proposed IPS mode cell. Therefore, we need a design compromise for the compensation of the increased threshold voltage in hexagonal electrode structure.

Figure 5 is a polar plot which illustrates the iso-contrast ratio (CR) contours of S-IPS and proposed novel electrode IPS mode cell, respectively, under their respective maximum transmittance voltages at a

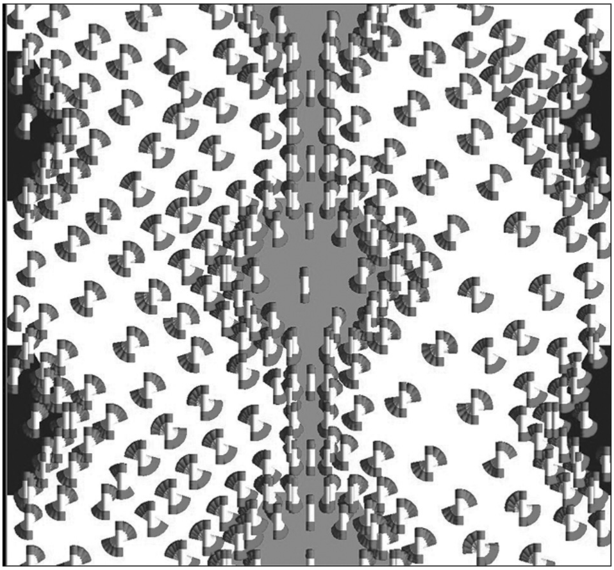

FIGURE 3 Top view of the director distribution on the liquid crystal layer when 7 V is applied.

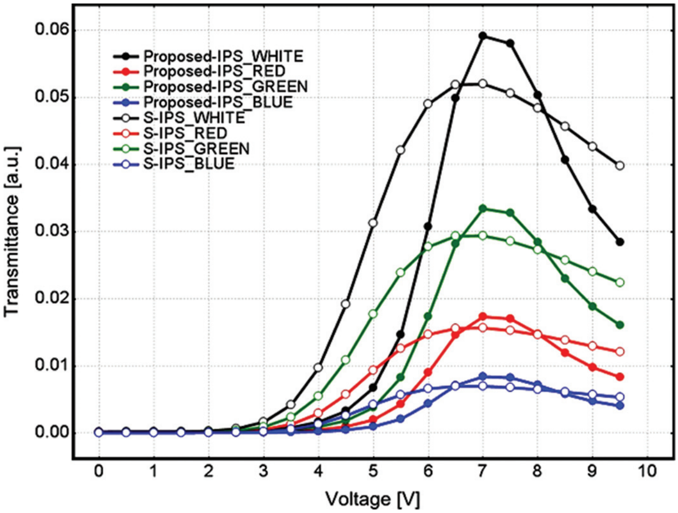

FIGURE 4 Voltage-dependent light transmittance curves for the conventional Super-IPS and the proposed IPS mode.

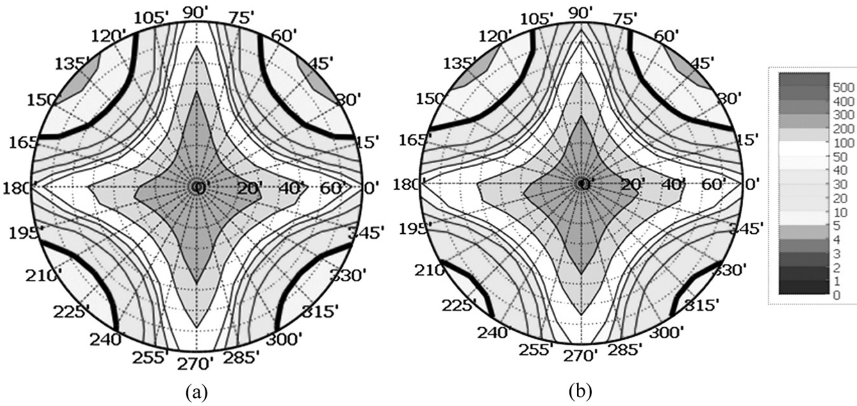

FIGURE 5 ISO-Contrast plots for (a) the S-IPS cell and (b) the proposed IPS cell.

wavelength $\lambda = 589\,\text{nm}$. The black line in each polar chart represents the contrast ratio wherein the value of CR is set 10. Even without the use of the compensation films, the viewing angle for $\text{CR} \geq 10{:}1$ has been found to improve when we compare the proposed IPS mode cell with the conventional S-IPS.

Referring to Figure 5(b), we can see that the proposed IPS structure exhibits a 350:1 contrast ratio at the volume which is defined by the $\pm 30^\circ$ view cone, and 10:1 at the volume which is defined by the $\pm 70^\circ$ view cone. In the meanwhile, the reference S-IPS exhibits a 300:1 contrast ration at the volume which is defined by the $\pm 20^\circ$ view cone and 10:1 CR at the volume which is defined by the $\pm 60^\circ$ view cone. Therefore, the simulation study implies that the proposed novel hexagonal IPS mode exhibits the wider viewing angle characteristics over the conventional S-IPS even without using any compensation films.

Figure 6 is a diagram illustrating the color difference as functions of the azimuth and polar angles for comparing the reference S-IPS mode cell and the proposed IPS mode cell. Referring to Figure 6(a), we can see that the white light is incident from the 45° and scanned across the whole azimuthal angle range. Referring to Figure 6(b), however, we see that the white light is scanned across the whole polar angle range at $\Phi = 90^\circ$. The calculated color difference is plotted in 1976 CIE coordinates. Referring to Figures 6(a) and 6(b), we can recognize that the hexagonal electrode IPS mode exhibits smaller color difference performance than the conventional S-IPS mode cell. An optimized device design will eliminate the color shift further.

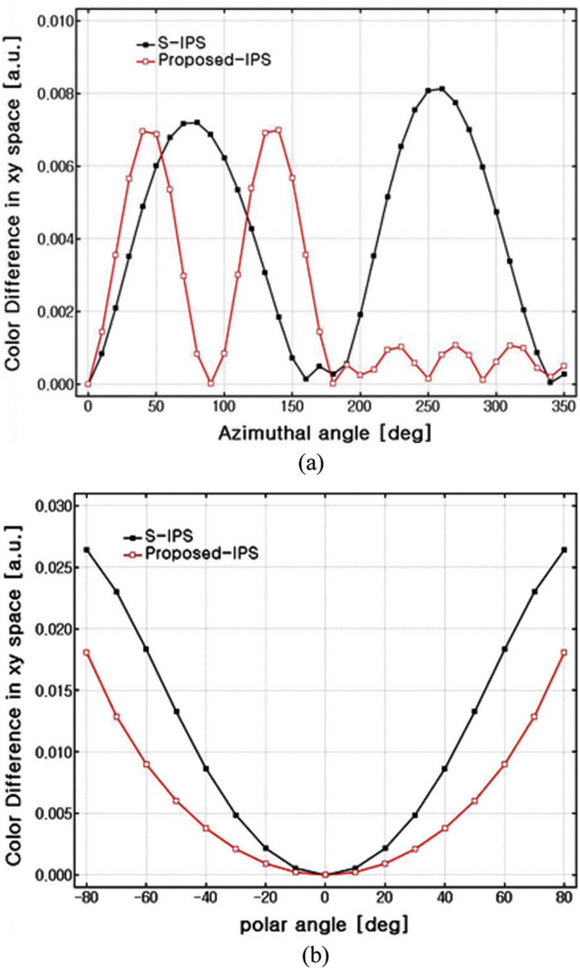

FIGURE 6 Dependence of color shift on viewing direction. (a) Dependence on the azimuth angle. (b) Dependence of color shift on viewing angle.

CONCLUSION

We devised a novel hexagonal IPS cell architecture which provides the wider viewing angle characteristics as well as the higher light transmittance in comparison to the traditional IPS cell. We looked into the electro-optical characteristics of the proposed architecture in detail including the voltage-transmittance (V-T) curve, contrast ratio (CR) for the optimal operation of the IPS cell. The transmittance of the proposed IPS cell is considered to be enhanced by 11.9% over the traditional S-IPS cell. Furthermore, the proposed IPS mode cell exhibits the wider viewing angle performance as well as less color shift when we compare with the traditional S-IPS architecture.

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