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# Static Configuration of the Super In-Plane Switching Liquid Crystal Director on the Electrode

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*In this work we investigate dynamic behavior of the LC director including the defect nucleation and the LC director field on the shape of the electrode using the Q-tensor method in the Super IPS cell. In general, the Q-tensor method can model the defect dynamics in a liquid crystal director field in addition to electrical behavior of the LC director.*

## 1. INTRODUCTION

The super–in plane switching (S-IPS) mode [1] has been widely used to various applications because of their excellent optical performance. In the early days, main issue of the S-IPS mode is how to increase the transmittance. So, the investigation is active about relations between the operating voltage and liquid crystal (LC) bulk area. Recently, To increase contrast ratio over 1:600, polarizer film, backlight sheet, color filter resin, taper angle of electrode, and rubbing conditions have all been investigated [2]. Especially, using the compensative film achieve the wide viewing angle, even though in the diagonal direction just like the true wide- IPS (TW-IPS) [3].

However, S-IPS mode has to apply muti-domain structures in a single pixel to their superior optical performance. Through multi-domain structures, we can easily get the wide viewing angle property, but multi-domain structures have also disadvantages. Precisely, multi-domain structures exhibit disclinations because of the spatial LC director field which has high elastic distortion energy due to the multi-domain effect.

Sometimes, disclinations cause a decrease of the optical transmittance of the multi-domain LC cell. Therefore, an understanding of the dynamic behavior of the LC director field has become important for advanced LC modes such as the S-IPS mode and the Patterned-VA (PVA) [4] mode.

In this work we investigate especially parts of the electrode's edge, electrodes patterned just like a "V" shape and around boundary of the multi-domain. From the result of simulation, the Q-tensor method [5] is similar to the real panel. Generally, LC dynamics are very unstable around the edge of the electrode, so that we can easily find the unstable disclinations. It is possible to control LC dynamics around the edge the electrode using different electrode shape. From experimental results we reveal, when we use the Q-tensor method we can design effective electrodes in the S-IPS mode.

## 2. OBSERVATIONAL RESULTS OF REAL PANAL

Figure 1 shows the photograph of the S-IPS cell. The liquid crystal with positive dielectric anisotropy ($\Delta n = 0.0846$ at $\lambda = 589\,\text{nm}$, $\Delta\varepsilon = 8.4$) from Merck was used in our experiments and simulations. The width of the electrodes was $3.5\,\mu\text{m}$, the distance between the electrodes was $11\,\mu\text{m}$, and the electrode angle was $70°$. The pre tilt angle generated by the rubbing is $2°$. The two glass substrates were then assembles to provide a cell gap ($d$) of $3.4\,\mu\text{m}$. Two polarizers are

(a)                      (b)
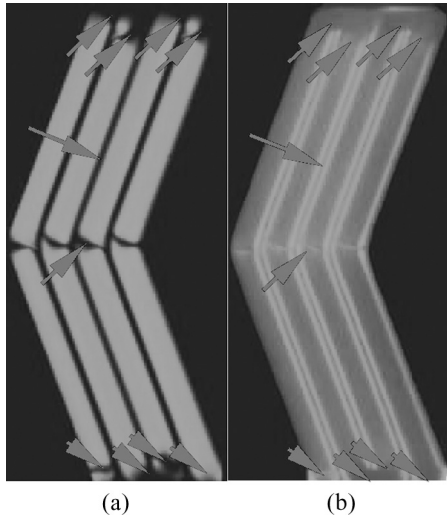
**FIGURE 1** Photograph of the super-IPS cell in the bright state: (a) with transmissive mode, (b) with reflective mode.

oriented to cross each other and one of them is aligned parallel to the rubbing direction.

Red arrows indicate disclination areas. We observed three types of disclinations. First is the disclianation is around the edge of the electrode. Second is the disclianation is on the electrode. And the last is the generated disclination at boundary of the multi-domain which located in middle area of the S-IPS cell. We found disclinations cause a decrease of the optical transmittance of the S-IPS cell because areas of the disclination were duskier than other areas at the white state.

## 3. SIMULATION AND EXPERIMENTAL RESULTS

Normally, conventional super-IPS cells do not have defect trap at the edge of the electrode, so we can observe unstable dynamic behavior because high strain energy can be stored in the very small area. Figure 2 shows the nucleated defect on the edge of the electrode.

In general, edge of the electrode can easily make the nucleation of the defect because the generated defect due to competition of the strain energy from the edge of the electrode move to upper right side by applying the voltage. Figure 2(a) and (b) shows microscopic photographs of the LC cell when applied voltage is 8 V and 10 V, respectively.
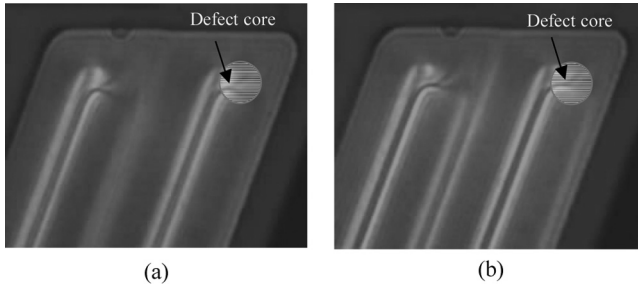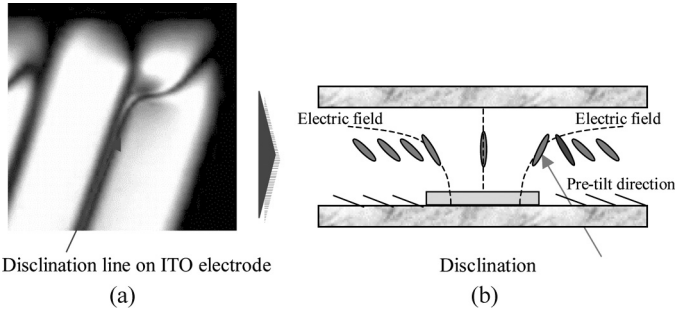
**FIGURE 2** Photograph of the generated defect cores around edge of the super-IPS LC cell: (a) with applied voltage of 8 V, (b) with applied voltage of 10 V.

Figure 3 shows the 3-dimensional modeling of the LC director field around the edge from the simulation by using fast Q-tensor method. We found the defect core moves to upper right side by applying the voltage. As a matter of fact the same result from when we observe the real panel. Figure 3(a) shows us the simulation result when
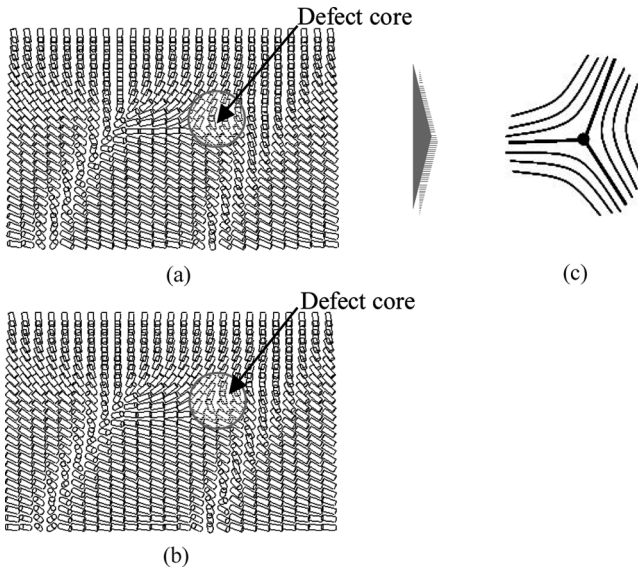


**FIGURE 3** Modeling of the LC configuration on the edge of the electrode in super-IPS LC: (a) When the applied voltage is 8 V, (b) When the applied voltage is 10 V, (c) cartoon of the modeling of the nucleated defect.

Disclination line on ITO electrode                    Disclination

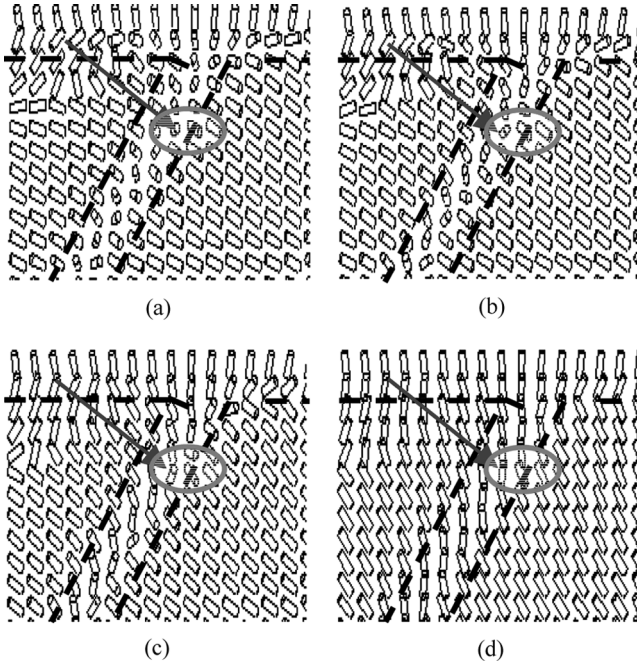(a)                                                              (b)

**FIGURE 4** The Disclination line on the electrode of the S-IPS cell: (a) Photograph of the disclination line on the electrode, (b) Cartoon of the electric field direction on the electrode.

applied the Vpp 8 V. Figure 3(b) shows us the simulation result when applied the Vpp 10 V. Figure 3(c) shows the LC director configuration can be modeled to defect with Frank index $n = -1$ and strength $s = -1/2$ [6].

Figure 4(a) shows the photograph of the disclination line on the electrode. Figure 4(b) shows the electric field's direction with LC directors. The LC director stands up by following the vertical electric field inn the middle of the electrode, so the defect nucleation has not been found. However, the LC director of the edge of the electrode moves to the electric field's direction. And then the LC directors of the bulk area have been affected by the pre-tilt's direction. Accordingly, the LC director field of two kinds of the areas are competed each other. The LC director field has the defect nucleation by stored strong elastic energy in the case of the edge around the electrode.
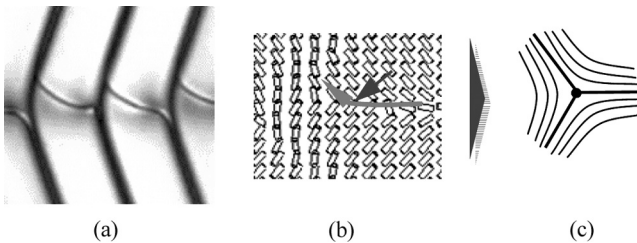
Figure 5 shows the Modeling of the LC configuration on the electrode in super- IPS LC cell. From Figure 5(a) to Figure 5(d) are modeling of the LC configuration each layer when we parted 10 layers from the LC layer. As the result of simulation, LC directors on the electrode stand up by following the vertical electric field according to the defect nucleation has not been found at lower LC layers. However, LC directors on the electrode has twisted by following the horizontal electric field defect nucleation by stored strong elastic energy at upper LC layers.

Figure 6 (a) shows the photograph of the boundary of the multi-domain in the middle area. We observed the disclination line which shape just like "S". Reverse rubbing makes "S" shape curve. The disclination on the upper electrode is caused by the small light-leakage. On the contrary, the disclination on the lower electrode is caused by

(a)                                    (b)

(c)                                    (d)

**FIGURE 5**  Modeling of the LC configuration on the electrode in super-IPS LC cell: (a) director modeling of the sixth layer, (b) director modeling of the seventh layer, (c) director modeling of the eighth layer, (d) director modeling of the ninth layer.

the large light-leakage. Figure 6(b) shows the Modeling of the LC configuration around boundary of the multi-domain in the middle area. It also shows the distribution of the director around boundary



(a)                    (b)                    (c)

**FIGURE 6**  Photograph with Modeling of the LC director in the middle area of the super-IPS LC cell: (a) Photograph of the disclination line in the middle area, (b) Modeling of the LC configuration around boundary of the multi-domain in the middle area, (c) Cartoon of the modeling of the defect.

of the multi-domain. For that reason, we investigate the LC director configuration can be modeled to defect with Frank index $n = -1$ and strength $s = -1/2$ [6]. That is Figure 6(c).

## 4. CONCLUSION

We observed three types of disclinations on the S-IPS LC cell. First is the disclianation around the edge of the electrode. Second is the disclianation is on the electrode. And the last is generated around boundary of the multi-domain which located in middle area of the S-IPS cell. Also we modeled three types of disclinations by using the Q-tensor method. For better optical characteristics of the LC cell, various structure of the LC cell should be considered because the defect, which is generated by the non-uniform voltage distribution by structure of the electrode, may cause the unpredictable optical loss because of generated defects.

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