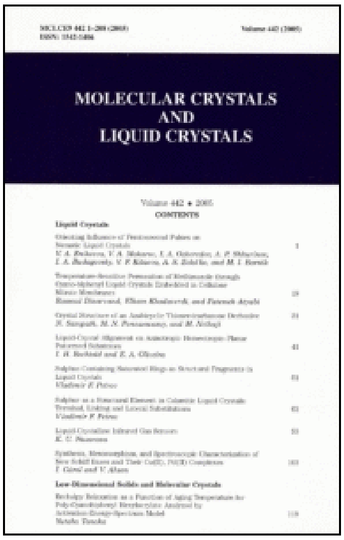

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Optimized Slit Pattern with Defect Trap for the Patterned Vertical Alignment Liquid Crystal Cell

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Dynamical behavior of the liquid crystal director on the slit of the patterned vertical alignment liquid crystal cell are very unstable because there is a strong competition of strain energy of liquid crystal director. In this paper, we proved a unit patterned vertical alignment cell with stable dynamic behaviors by using the defect trap structure experimentally. In addition, we also inspected electro-optical instability of the proposed patterned vertical alignment liquid crystal cell as functions of a width and a length of the slit pattern. As a result, we could optimize the slit pattern of the patterned vertical alignment liquid crystal cell with the defect trap.

Keywords Defect; patterned vertical alignment liquid crystal cell; slit pattern

1. Introduction

Liquid Crystal Displays (LCDs) account for an enormous position in the flat panel display market, and nowadays the scale of LCD market is rapidly growing. LCD TV among various LCDs has the advantages of high resolution, light weight, slim thickness, etc. In order to maximize electro-optical characteristics, many companies and research groups have been developing advanced technology by using the advanced liquid crystal (LC) mode such as in-plane switching (IPS) [2], fringe-field switching (FFS) [3], multi-domain vertical alignment (MVA) [4], patterned vertical alignment (PVA) [1] and so on. In addition, Samsung Electronics exhibits the proto type LCD using polymer-stabilized blue phase liquid crystal (BPLC) at SID 2008. The polymer-stabilized BPLC [5] has great advantages such as fast response time, simple fabrication process and wide viewing angle. On the contrary, it still has major challenges to be overcome such as a high driving voltage and a lower optical efficiency for successful production [6].

Among LC modes, the PVA mode is one of the best approaches in commercially available LCDs. In the OFF state, the molecules are normal to the two bounding

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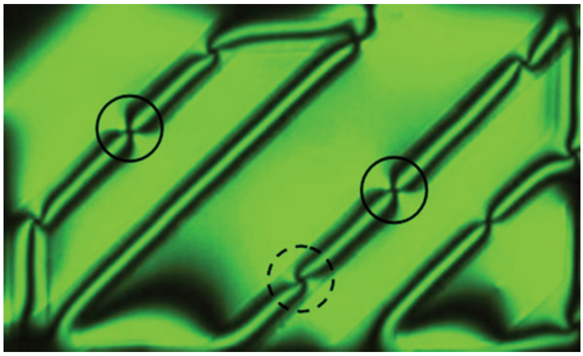

Figure 1. Microscopic photograph of the conventional PVA cell. (Figure appears in color online.)

plates. Thus, the phase retardation of the cell is zero. An electric field applied to the bounding plates tilts the molecules and causes optical retardation; the material is of a negative dielectric anisotropy. Chevron-shaped patterned electrodes produce a fringe electric field with the in-plane component that directs the molecular tilt in the ON state. The resulting multifold symmetry of director field gives an excellent viewing angle performance, high transmittance, and contrast ratio. On the contrary, we can easily find that the multi-domain effect also gives us the unstable defect generation in that active area of the PVA cell. In order to fix the unstable generated defect in the slit of the PVA cell, a notch pattern can be used in the slit. In the previous paper [7], however, we figure out that the PVA cell with notch structure generated other unstable LC configuration in the slit when applying voltage. Figure 1 shows the microscopic photograph of the conventional PVA cell at 4 V. We can find out two defects on the slit area. The solid circles in Figure 1 shows the fixed defects by notch structures and these have a role to fix the unstable defect generated along the slit. However, this structure can also make the other defect between the notch structure around the center of the slit and the edge of the slit. The dotted circle in Figure 1 represents the generated defect due to the notch structure.

So we proposed a new slit edge design to push a defect core out the active area which was generated by the notch structure and edge on the wing pattern by using the commercial software "*TECHWIZ LCD*" (Sanayi system, Korea), which applies the Q-tensor method to calculate the LC director field. In this paper, we proposed a unit PVA cell with very stable dynamic behaviors by using the defect trap structure experimentally. In addition, we also inspected electro-optical instability of the proposed PVA LC cell as functions of a width and a length of the slit pattern.

2. Experimental Verification of the Effect of the Defect Trap Structure

Figure 2 shows the microphotograph of the prepared unit PVA cell pattern with defect trap structure. The dotted circle presents the defect trap structure at the slit edge area. As shown in Figure 2, the defect trap can make a voltage distribution around the defect trap very non-uniform, so that this can induce the defect generation around the defect trap compared to the other position along the slit line. The distance between the slit is 20 μm and the width of the slit is 10 μm. We use

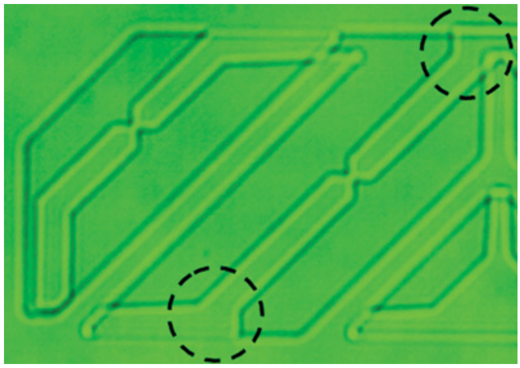

Figure 2. The pattern of the PVA LC cell with defect trap structure. (Figure appears in color online.)

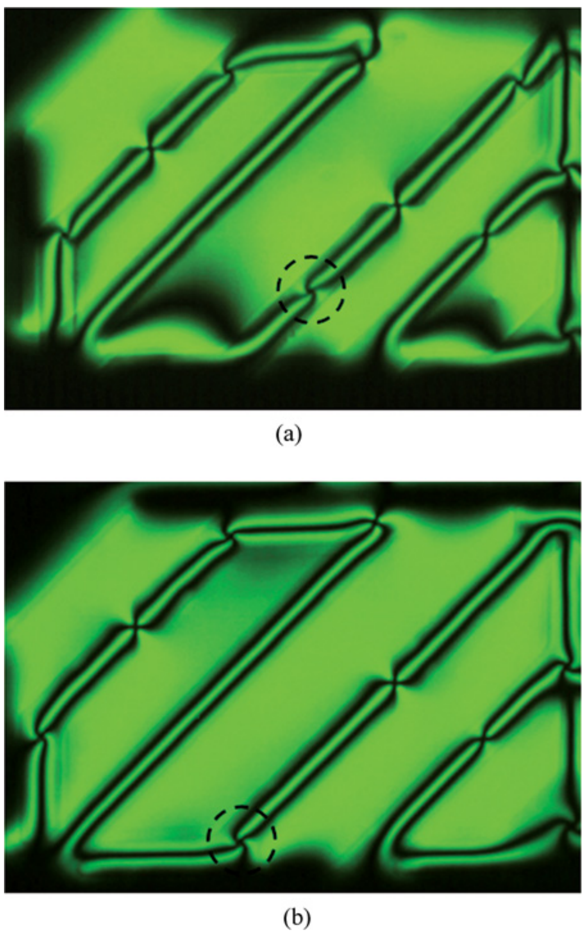

Figure 3. Optical transmittance of the fabricated PVA LC cell at the white state: (a) the conventional cell at 4 V, (b) the proposed cell at 4 V. (Figure appears in color online.)

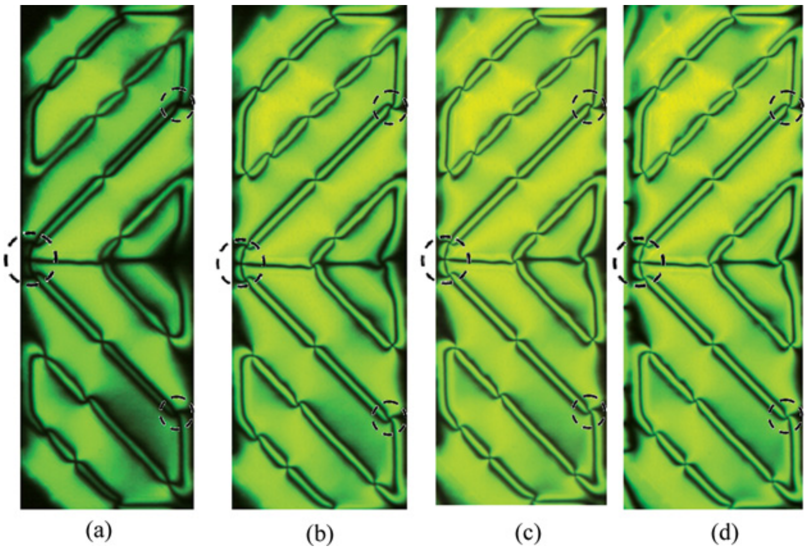

Figure 4. Optical Transmittance of the fabricated PVA LC cell with the defect trap structure: (a) at 4 V, (b) at 6 V, (c) at 8 V, (d) at 10 V. (Figure appears in color online.)

4 μm ball spacer to set uniformly cell gap. As an alignment layer, AL60702 manufactured by JSR in Japan is spin-coated on the top and bottom indium-tin oxide glass substrates. The parameters of the used LC are as follows: $k_{11} = 12.7$ pN, $k_{22} = 6$ pN, $k_{33} = 15.3$ pN, $\gamma = 0.133$, $\varepsilon_{\|} = 3.6$, $\varepsilon_{\perp} = 7.4$.

Figure 3 shows the optical transmittance of the prepared unit PVA cell at the bright state. The dotted circles in Figure 3 show the generated defect by notch structure in the slit. Compared to the generated defect of the conventional LC cell as shown in Figure 3(a), the generated defect of the proposed LC cell is obviously moved to the edge of the slit which is a almost out of the active area as shown in Figure 3(b). In order to observe the dependence of the applied voltage, we have changed the applied voltage from 4 V to 10 V. Figure 4 shows the experimental microphotographs of transmittance as a function of the applied voltage. The dotted circles in Figure 4 represent the generated defect on the slit of the LC cell. We could observe that the generated defects are fixed at the edge of the slit of the cell even if we increase the voltage because of the defect trap at the edge of the cell. Therefore, we can expect the stable dynamical behaviors of the LC director due to the notch structure and defect trap slit edge because the proposed structure can fix the generated defect when we apply the voltage. From these results, we can confirm that the defect core keeps their position in the defect trap area regardless of the applied voltage.

3. Optimization of the Slit Pattern of the LC Cell

In this paper, we also investigated how we can increase the length of the slit and we can reduce the width of the slit of the cell due to the proposed defect trap compared to the conventional cell because this effect strongly related to the aperture ratio of the cell. Investigation of the optimization of the slit pattern of the LC cell has been performed by the calculation.

In order to achieve the equilibrium state of LC configuration, we need to calculate the minimum free energy. For the calculation of the free energy, the Gibb's free energy of the LC cell is commonly used. The Gibb's free energy consists of elastic energy and electric energy. In general, the elastic energy can be expressed with Oseen – Frank vector representation that uses three elastic constants (splay, twist, bend) and Q-tensor representation method [8–12]. However, the Oseen – Frank equation with vector form can not exactly describe the director orientation in the local area where stores high elastic deformation energy because the equation depends on the sign of the unit vector describing the director field. On the contrary, recent studies have provided that the numerical modeling method with the Q-tensor form can exhibits more exact results in the local area with high deformation energy, which may induce the defect and the phase transitions between topologically different states [13]. As for the PVA cell, it also contains local points on the slit with very high elastic deformation energy by applying the voltage, so that the Q-tensor method can be more suitable for modeling of the LC director configuration in the PVA cell.

In order to investigate the optimization of the slit width and the length between the notch structure and defect trap structure, we use the Q-tensor method to calculate the LC director field. Figure 5 shows the results of defect dynamics on the slit pattern as a function of the length between the notch and defect trap. From the Figure 5, we can understand the notch position can increase by 30 μm from the defect trap because we also find out another defect pair in the slit from 35 μm.

And then, we also optimized the width of the slit by investigating the defect generation as a function of the width of the defect. As I mentioned before, width of the conventional slit pattern is 10 μm. We observed the generated defect by reducing the width of the slit of the conventional and the proposed cell to 8 μm and 7 μm. Figure 6 shows calculated results of the optical transmittance of the PVA slit as a function of the width of the slit. As shown in Figure 6(a), the conventional LC cell exhibits another defect pair if we reduce the slit width to 8 μm from 10 μm. On the contrary, we can easily observe the proposed structure can make us reduce the slit width to 8 μm as shown in Figure 6(b). However, 7 μm of the slit width also makes another defect pair even if we apply the defect trap on the slit. Therefore, we can understand that the defect trap at edge can induce the defect generation at edge of the slit and this effect can permit the length of the slit longer and the width of the slit narrower compared to the conventional LC cell.

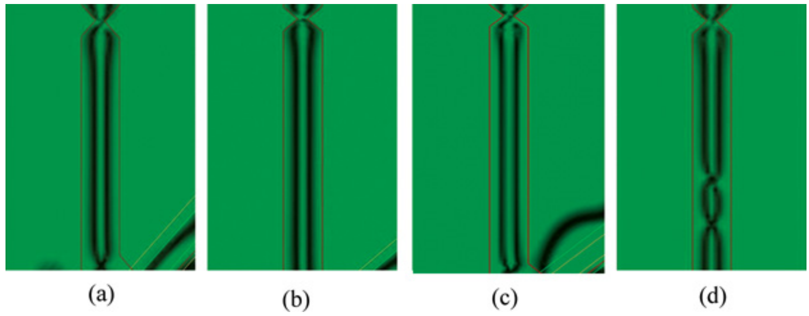

Figure 5. Calculated optical transmittance as a function of the length of the slit: (a) reference (20 μm), (b) 25 μm, (c) 30 μm, (d) 35 μm. (Figure appears in color online.)

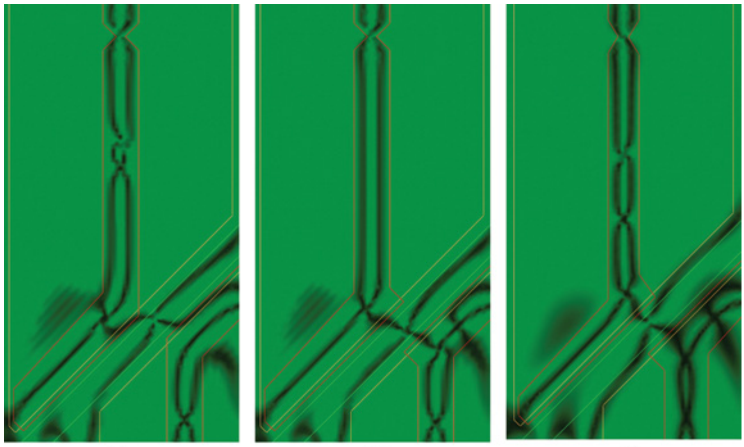

Figure 6. Calculated optical transmittance as a function of the width of the slit: (a) the conventional cell with 8 μm of the slit width, (b) the proposed cell with 8 μm of the slit width, (c) the proposed cell with 7 μm of the slit width. (Figure appears in color online.)

4. Conclusion

In conclusion, we fabricated the unit PVA cell including the defect trap structure to confirm the effect of the defect trap structure and observed that the induced defect on the slit edge could fix the generated defect on the outside of the active area even if the applied voltage is increased. Also, we optimized the appropriate condition of the silt length and width within effect of the defect trap structure using modeling of the director by simulation results. This technology that can control the dynamical behavior of the generated defect in the active area can be widely applied to the other advanced LC mode such as the BPLC which requires low driving voltage and high optical performance by controlling the disclination line and double twist cylinder in BPLC.

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