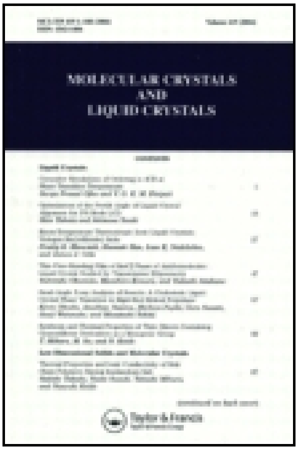

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A Novel Vertical Alignment Display

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Vertical alignment display is of interest in a view point of fast response time with wide viewing angle and rubbing free displays. We have fabricated a new vertical alignment display driven by fringe field with initially biased surface boundary condition on one side of substrate. The device exhibits interesting molecular dynamics depending on biased state when the voltage is applied. In this paper, the electro-optic characteristics and molecular dynamics of novel cells will be discussed.

Keywords: fringe field; vertical alignment; molecular dynamics

INTRODUCTION

Active matrix liquid crystal display (AMLCD) is applied to note-book, monitor, and recently TV, trying to replace cathode ray tube (CRT). But the basic requirements of the LCD to replace CRT are wide viewing angle, high brightness and fast response time. In order to realize these requirements, in-plane switching (IPS) [1], optically compensated bend (OCB) [2], multi-domain vertical alignment (MVA) [3], dual-domainlike vertical alignment (DDVA) [4] and fringe-field switching (FFS) [5] are introduced. Especially, the FFS device that utilizes fringe field shows high light efficiency with wide viewing angle unlike the conventional IPS mode. Recently, the lateral field induced vertically aligned (LFIVA) as the new wide-viewing angle VA device that the device is consisted of slit patterns in the pixel electrodes to generate lateral component of electric field around the slits on bottom substrate and rubbing of the top substrate with common electrode, is reported [6].

In this paper, we investigated the molecular dynamics of the LC director and electro-optic characteristics of the fringe-field switching device with vertical alignment (FFS-VA) with one-side rubbing by simulation and experiments.

EXPERIMENTAL, RESULTS AND DISCUSSION

In our study, the cell structure is the same as that of the FFS device as shown in Figure 1. That is, the electrodes are existed only on bottom substrate and the pixel ITO is patterned in a slit form, above the dielectric layer with counter electrode below it. We use a nematic LC with negative dielectric anisotropy from Merck (Δn=0.077 at λ= 589nm, 20℃) and $\Delta\varepsilon$= -3.8 (20℃, 1kHz)) and vertical alignment material from Japanese Synthetic Rubber (JSR) for preparation of the test cells. The molecular dynamics of the FFS-VA test cells with one-side rubbing and no rubbing are investigated using polarizing microscope and the electro-optic characteristics were measured using LCD 7000 (Otsuka, Japan). We also performed a simulation using 2DIMMOS (Atronic-Mechers GmbH, Germany) to understand the LC dynamics. The biased conditions of the test cells are shown in Table 1 with rubbing angle (Θ) between the rubbing direction and the direction parallel to the patterned ITO.

In vertical alignment display, the light transmission is proportional to $\sin^2(2\chi)$, where χ is an angle between the optic axis of the LC director and the transmission axis of crossed polarizers. Figure 2 shows simulation results with a light transmittance and LC molecular deformation for the test cell (# 2) rubbed with Θ=0° on top substrate.

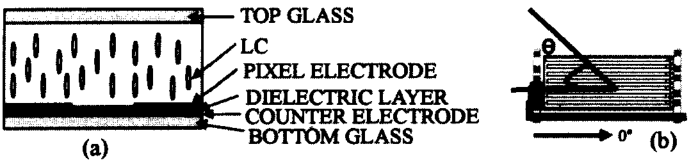

FIGURE 1. The cross-sectional view (a) and top view with rubbing angle (Θ) (b) of FFS-VA cell structure.

TABLE 1. The prepared conditions of the test cells.

No. of Cell	Rubbing Side	Rubbing Angle (Θ/ °)
1	No	-
2	Top	0
3	Top	90
4	Bottom	0
5	Bottom	- 45

Figure 2(a) is the result when the angle (ϕ) between one of the optic axis of crossed polarizers and the parallel direction to patterned pixel electrode is 0°, and Figure 2(b) is the result when the ϕ is 45°. For ϕ= 0°, the light transmittance near the edges of pixel electrodes and at the center of electrodes is zero as indicated by solid thick and narrow lines. This indicates that the azimuthal angle (A.A.) of the LC director is coincident with one of optic axis of the polarizer, that is, into or out of the paper. However, there is small amount of light leakage in the area between the edge and center of electrodes, indicating that the A.A. is not in horizontal or vertical direction. Now when we rotate the crossed polarizer to 45°, the light transmittance occurs in whole area with slight oscillation, meaning that most of the LC director tilt down to rubbing direction with χ, 45°. Also, the microphotographs of the prepared test cell (# **2**) with applied operational voltage are showed in Figure 3. The transmittance pattern including the disclination lines is appeared depending on the position of the crossed polarizer, which is consistent with the simulation result. In Figure 3(b) with ϕ=0°, the thick and narrow solid lines meaning the strong and weak disclination lines respectively, exists giving rise to low transmittance. However, when the axis of polarizer is rotated to 45°, the transmission becomes higher though it oscillates. We can also observe the dark lines at the corner of pixels coming from inhomogeneous fringe field in that area.

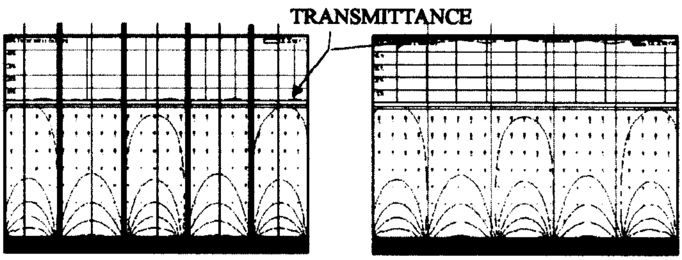

FIGURE 2. The simulated results of the FFS-VA with the rubbed top substrate of Θ=0° when ϕ is 0 °(a) and 45 °(b).

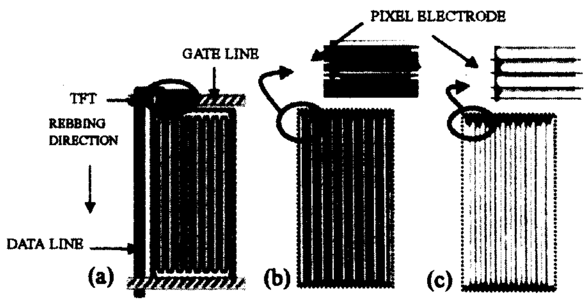

FIGURE 3. The transmittance microphotographs of a top-view pixel structure (a), the cell (# 2) (Θ=0 °) with ϕ= 0 ° (b) and 45 °(c). (The solid and dash lines are the disclination lines.) See Color Plate X at the back of this issue.

Again, we have taken photos of one thin-film transistor (TFT) pixel of the cell by increasing voltage as shown in Figure 4. When no voltage is applied, the transmittance is zero, that is, perfect dark state. By increasing the applied voltage, light starts initially from the area above center of the electrodes, and then extends to the other areas between electrodes. However, as we can observe disclination lines in gray levels (see Figure 4(b) and (c)), the LC dynamics of the FFS-VA device is unstable due to disturbing field by gate and data line of TFT and also field at the edge part. Nevertheless, it disappears with further increasing voltage, shown in Figure 4(d). Therefore, optimizing the disturbing field in the pixel of FFS-VA device is very important to obtain a high quality device.

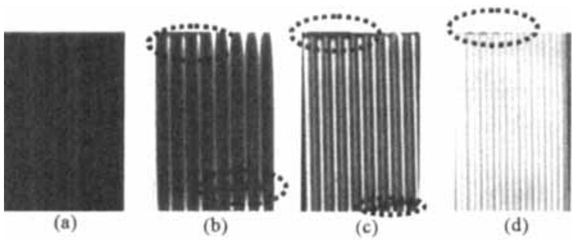

FIGURE 4. The polarized microscopic photographs of the cell (# 2) (Θ= 0 °, Φ= 45 °) at the off-state (a), 6 V (b), 9V (c) and 15V (d). See Color Plate XI at the back of this issue.

Base on the simulational and experimental results, we establish the model for molecular dynamics in the FFS-VA mode with one-side rubbing. Figure 5 shows the configurations of the LC directors and disclination lines in the FFS-VA cell at on-state and off-state including the induced electric field.

The test cells with various rubbing angles are measured for voltage dependent transmission (V-T) characteristics as shown in Figure 6.

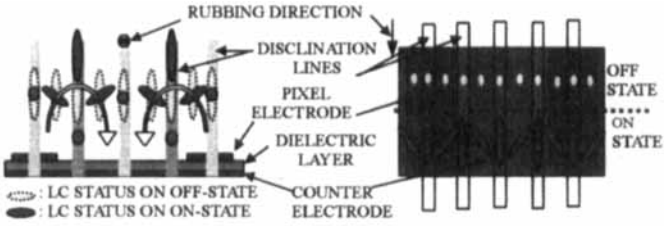

FIGURE 5. The configuration of the LC director in the FFS-VA mode. (a) Cross-sectional view and (b) top view.
See Color Plate XII at the back of this issue.

Compared to no-rubbing cell (# 1), the other cells with one-side rubbing have relatively higher transmittance. From these results, we confirmed that one-side rubbing in the FFS-VA mode enhances the light transmittance, that is, deciding the tilt-down direction with biased surface boundary. Especially, the cells with Θ=0° and ϕ=45° show the highest brightness.

Based on these results, we will work on the 2-domain FFS-VA with wedge shape of only pixel electrode for better wide-viewing angle and the stabilization of LC dynamics for the stabilization of the device. Also, we can simplify the cell process by one-side rubbing.

SUMMARY

We have fabricated a new FFS-VA mode with the FFS electrode structure and one-side rubbing. We have studied the molecular dynamics of the cells with several biased conditions. The cell with one-side rubbing shows higher transmittance than that of no-rubbing cell. The device is advantage in the aspect of high brightness with simple process and can exhibit wide-viewing angle with 2-domain FFS-VA. However, the stabilization of the LC dynamics is necessary to be applicable to TFT-LCD.

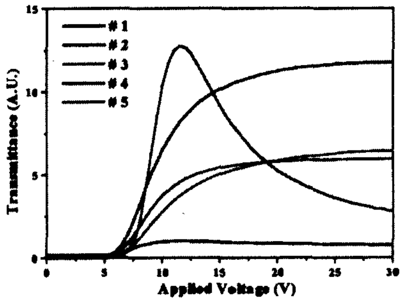

FIGURE 6. The V-T characteristics for the several FFS-VA cells. See Color Plate XIII at the back of this issue.

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