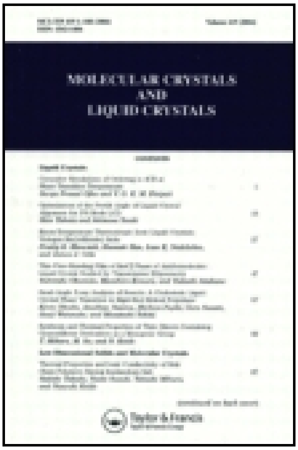

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Characterization of a Homeotropic 4-Domain Liquid Crystal Cell Which Uses Oblique Electric Field

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Homeotropically aligned liquid crystal (LC) cell with different area electrodes to produce oblique electric field has been fabricated and characterized. Four domain structure is successfully obtained as a simulated result and the LC cell shows wide viewing angle characteristics. Its dynamic process on applying electric field consists of two steps, the fast step where the LC molecules fall down to the substrate and the slow step where the LC molecules change their azimuthal direction. Introducing a black reset pulse which makes the slow process invisible will give favorable effects on both the response speed and motion picture images.

Keywords: Liquid Crystal Display; Wide Viewing angle; Multi-Domain; Homeotropic Alignment; Reset Pulse

INTRODUCTION

Wide viewing angle characteristics are necessary for large size liquid crystal display devices (LCDs). To achieve wide field of view, optical compensation film for twisted nematic mode[1], multi-domain structures[2], optically compensated bend mode[3] and in-plane switching mode[4] are suggested and some are produced. Fast response speed, as well as, wide viewing angle characteristics is desired for LCDs and a lot of modes are investigated seeking for better performance. Homeotropic alignment LCD has advantages, such as, high contrast is easily obtained since its retardation is 0 independent on cell thickness, fast response will be realized by reducing cell thickness. Multi-domain structure is necessary to achieve a wide field of view for a homeotropic LCD. A few methods have been shown to make a multi-domain structure, for example, making protrudes on substrates[5], cutting slits into ITO electrode[6]. Photolithography process leads to higher cost, and it should be avoided as much as possible. We have investigated a multi-domain formation effect of the oblique electric field which is produced by the area difference in the upper and the lower electrodes. If multi-domains are stably formed only by the area difference, no additional process is necessary to the conventional LCD production, and what is more, rubbing process is eliminated, which fact will leads to cost reduction. In this paper, we will report a four-domain formation in the LC cell which uses oblique electric field using simulation and test LC cell experiment. We have also analyzed the dynamic properties of the four domains using stroboscope measurement.

EXPERIMENTAL

Simulation

The expected effect of the oblique electric field is dividing a pixel into four regions. The upper electrode is larger than the lower electrode, and hence, the oblique electric field is produced at each edge of the four sides in the rectangular lower electrode. In TFT structure, the upper electrode has practically infinite area. In the simulation, we assume 64 μm X64 μm upper electrode and 56 μm X56 μm lower electrode, and the pretilt angle is 90 degree, the LC cell thickness is 5 μm, the applied voltage is 4 V. The simulation is 3 dimensional and the LC physical properties are listed in Table 1. The equilibrium sate has been simulated.

$\varepsilon \parallel$	$\varepsilon \perp$	ne	no	K11	K22	K33
3.6	7.8	1.559	1.476	16.7	20	18.1

TABLE 1. Physical properties of the LC used for the simulation.

LC Cell Fabrication and Evaluation

Only the lower substrate is fabricated using photo-lithography, whose structure is shown in Figure 1. The whole area of the upper substrate is covered with ITO. In order to apply different polarity voltages to the neighboring pixel ITO electrodes, two kinds of wires are connected to the electrodes, where each layer is separated with a SiNx insulating layer. The width of each wire is 6 μm. Each pixel is 60 μmX60 μm large has a 5 μmX5 μm contact hole at the center and has a 6 μm separation from the neighboring pixel. Another kind of pixel has been fabricated to check the effect of a dent on the LC boundary stability. An X shape trench pattern is fabricated in the SiNx layer and the resulting X shape dent of the ITO electrode is expected to work as pinning the LC boundary. Homeotropic alignment layer JALS2021 supplied from JSR corporation is coated on both the upper and the lower substrates, no rubbing process is applied and after dispersing 4 μ

m-diameter spacers, an LC cell is fabricated using sealing agent as a usual LC cell, and then, LC material with negative dielectric anisotropy is injected.

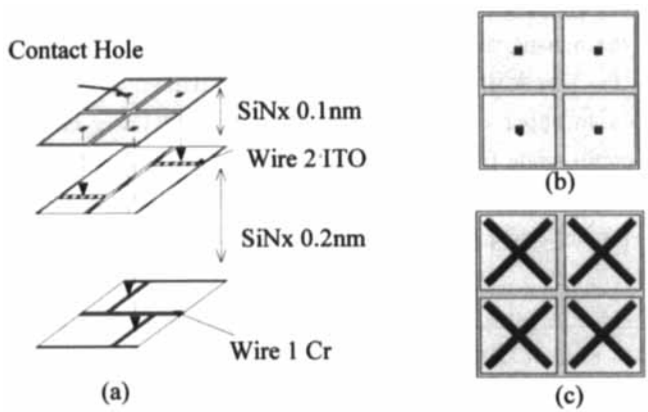


FIGURE 1 The lower electrode structure (a)Bird's eye view of ITO electrode and wires. (b) Electrode with contact hole. (c) Electrode with X shape dent.

LC alignment is checked with applying alternating rectangular current with 60Hz frequency and 5V amplitude to wire 1 and the same current whose phase is different by half period to wire 2 while keeping the counter common electrode as 0V. The polarizers are set as their transparent axes lie 45 degree and 135 degree from the bottom side of the electrode. Viewing angle characteristics are measured without a compensation film at various voltages.

Dynamical properties are investigated with following the transmitted light intensity change using stroboscope. Bias voltage (Vbias) is applied for 500ms before the driving voltage (Von) application which has the same wave form as LC alignment experiment and strobo photos are taken at appropriate intervals after this Von application.

RESULTS AND DISCUSSION

Simulation

The simulated results are shown in Figure 2. Homeotropically aligned LC molecules obey oblique electric field, and hence, each pixel has been divided into 4 regions where the LC molecules align almost perpendicular to each side of the rectangular electrode. The boundary regions coincide with the diagonal lines in which region the LC

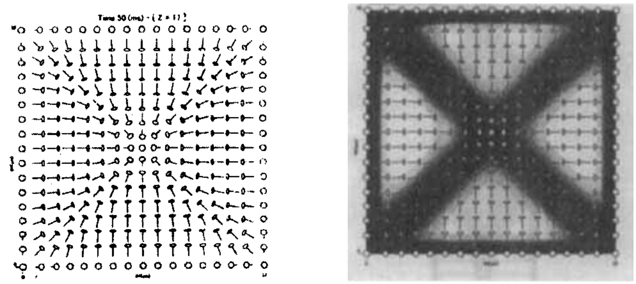
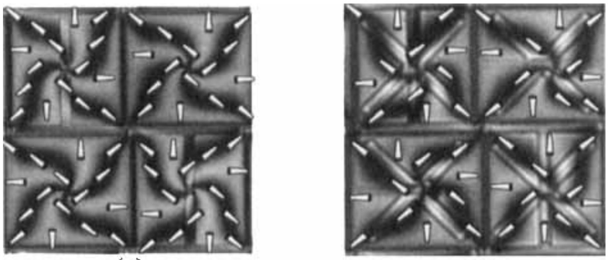


FIGURE 2. The simulated results of homeotropically aligned LC under oblique electric field. (a) LC directors (b) transmitted light intensity.

molecules decline toward the electrode center along the diagonal directions.

LC Cell Results

The observed LC orientation for the fabricated LC cells are shown in



(a) (b)

FIGURE 3. Transmitted light distribution and LC director orientations of (a) electrode with contact hole (b) electrode with X shape dent.

Figure 3. The deduced LC director orientations are also shown. Each pixel is divided into 4 regions and their boundaries are along the diagonal directions of the electrode which fact is in accordance with the simulated results. However, for the LC cell, the boundary regions form whorls instead of straight lines which feature is a quite remarkable difference between the simulation and the experiment. The dents whose depth is around 0.3 μ m in the ITO electrode are not effective for pinning the LC boundaries as shown in Figure 3 (b). Though the trenches are fabricated along the diagonal directions, the LC boundaries form whorls as on the flat electrodes without the dents. One interesting feature is that the contact hole whose depth is also 0.3 μ m does have the effect of pinning the boundary center which is seen in Figure 3 (a), although the boundary centers deviate to and fro in Figure 3 (b).

The typical result of the viewing angle characteristics is shown in Figure 4. The LC director orientations are the same as in Figure 3. As is expected for the homeotropic 4-domain LC cell, the field of view is quite wide and symmetrical. Though the viewing angle characteristics are not perfectly symmetrical because of the whorl shape boundaries, they are practically sufficient for usual use.

The time evolution of the transmitted light distribution for two different bias voltages obtained with stroboscope measurement is shown in Figure5. The transmitted light intensity takes maximum around 20ms (Vbias=0V) and 10ms (Vbias=2.2V) and gradually decreases to the equilibrium state. It is clearly seen that the LC molecules move with two steps, that is, the fast step where the LC molecules fall down toward the substrate and the very slow second step where the LC molecules change their azimuthal direction till they finally form the whorl shape. This characteristic is clearly seen for

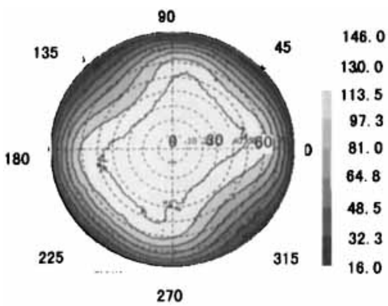


FIGURE 4. Iso-luminance curves of the LC cell at 5V.

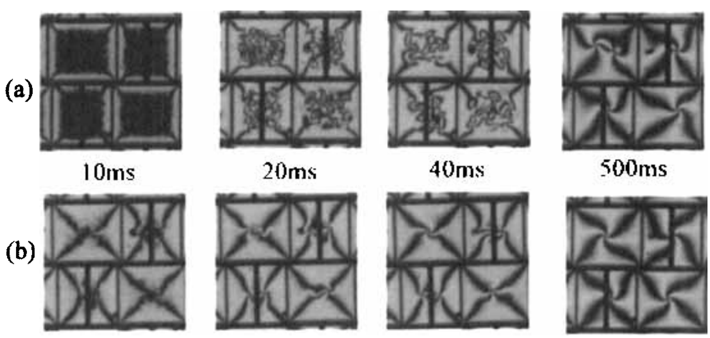


FIGURE 5. Changes in the light intensity distribution of the LC cell (a) Vbias=0V (b)Vbias=2.2V

the Vbias=0V case. When Vbias is 2.2V which is close to the threshold voltage, the LC fluctuation in the azimuthal angle is much less than the former case, but it still exists. Applying a black reset pulse is suggested to achieve sharp motion images for LCDs[7]. This reset pulse will eliminate the slow LC movement, and hence, the response speed becomes practically high for the 4-domain homeotropically aligned LC mode. Thus, the LCD which gives wide field of view and fast response will be obtained using a properly designed homeotropic LC mode.

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