A Nematic LCD with Submillisecond Gray-to-gray Response Time

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Abstract

We propose a triode structure for achieving submillisecond gray-to-gray response time in a double fringing-field-switching (DFFS) cell. The bright and dark states are obtained by applying a fringing field and a vertical field, respectively. The simulated averaged grayscale rise time is 793 μs and decay time is 478 μs. This triode DFFS mode enables conventional nematic LCDs for color sequential displays, 3D displays, and other photonic applications.

Author Keywords

Fast response, nematic liquid crystal, triode.

1. Introduction

The relatively slow response time (~5ms) of nematic liquid crystal displays (LCDs) cause motion picture image blurs, color breakup when considered for color sequential displays, and crosstalk for 3D displays. A color sequential display does not require spatial color filters so that its optical efficiency and resolution density are all tripled. However, to suppress color breakup the response time should be faster than 1 ms [1,2]. For 3D displays, which requires higher frame rate than 2D displays, submillisecond response time helps to reduce crosstalk and image blurs [3,4]. Thus, it is highly desirable to develop LCDs with submillisecond gray-to-gray (GTG) response time.

For a nematic LC device, the rise and decay times between gray level transitions can be written as [5]:

$$\tau_{rise} = \tau_o / [(V / V_{th})^2 - 1], \quad (1a)$$

$$\tau_{decay} = \tau_o / |(V_b / V_{th})^2 - 1|, \quad (1b)$$

$$\tau_o = \gamma_1 d^2 / K\pi^2, \quad (1c)$$

where V is the applied voltage to the final gray level, V_b is the bias voltage of the initial gray level, V_{th} is the threshold voltage, γ_1 is the rotational viscosity, and K is the corresponding elastic constant which depends on the LC alignment. For example, for an in-plane-switching (IPS) cell, $K=K_{22}$, which is the twist elastic constant. From Eq. (1), the response time of an LCD could be very slow when the grayscale voltages are close, especially in the vicinity of threshold.

As compared to the turn-on process, which is electric-field driven, the relaxation process is generally slower because it is mainly governed by the elastic restoring force. In order to reduce response time, various approaches, such as thin cell gap [6,7], crossed-field effect [8-10], overdrive and undershoot voltage [11,12], and bend mode [13,14], have been developed. However, each approach has its own merits and demerits.

In this paper, we propose a triode double fringing field (triode DFFS) mode to achieve submillisecond GTG response time. The bright state and the dark state are obtained by applying a fringing field and a vertical field, respectively. Using a commercially available LC mixture, our simulated averaged GTG rise time is 793 μs and decay time is 478 μs at the room temperature (~22°C).

2. Device Structure

Figures 1(a) and 1(b) depict the device structures of the proposed triode DFFS mode in bright and dark states, respectively. Each substrate has a planar common electrode and stripe pixel electrodes, same as the conventional fringe field switching (FFS) structure [15]. The typical electrode width and electrode gap is 2-5 μm, while the LC cell gap is 10-14 μm, depending on the LC material employed. To enhance the optical efficiency and transmission uniformity, the top and bottom pixel electrodes are intentionally shifted by half a pixel electrode width in order to form complementary domains on two boundary layers. To obtain a good dark state for wide-view purpose, the LC cell is configured between two crossed polarizers and a set of compensation films.

To obtain a good initial dark state, the LC directors are vertically aligned. When the voltages of the top and bottom pixel electrodes

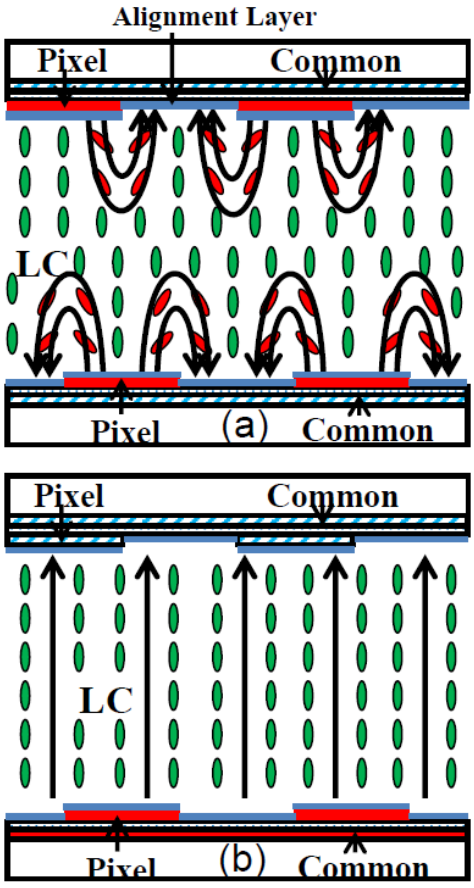

Figure 1. Device structure of the triode DFFS mode in bright (a) and dark (b) states. The LC employed has a positive Δε.

are switched on, e.g. from 0V to 10.8V to reach the highest gray level, an in-plane electric field pattern is generated and the LC directors are reoriented by the field, as shown in Fig. 1(a). The incident linearly polarized light experiences phase retardation and is transmitted by the crossed analyzer. Since the electric field can only penetrate a certain depth into the cell and allow switching the LCs within "penetration depth", the cell gap of the triode DFFS is intentionally set to be larger than the total penetrating depth of the top and bottom fringing fields. Therefore, the boundary layers are reoriented by strong electric field near the substrate surface, while the middle bulk layers function as standing layers, also known as "wall molecules".

During relaxation period, as depicted in Fig. 1(b), a voltage of 11V is applied to the bottom common and pixel electrodes to generate a vertical electric field while the top common electrode is always grounded. In addition to the surface anchoring force (due to elastic constant K_{33}), two forces help to accelerate the relaxation process. The middle standing layers, which act as strong boundaries, would induce high restoring forces (due to elastic constant K_{11}) on the switched LC molecules upon the removal of the in-plane electric field. And, the vertical field would also exerts a strong torque to pull the LC directors back to the vertical direction in addition to the existing elastic restoring torque, thus achieving submillisecond decay time. Also, because LC directors are vertically aligned, a high contrast ratio (>5000:1) can be obtained easily.

3. Results

The device structures and performance of the proposed triode DFFS mode are optimized using a commercial three-dimensional LC simulator TechWiz and the optical calculation is based on the extended 2×2 Jones matrix [16]. The device parameters are listed as follows: cell gap d=14 μm, electrode width W=3 μm, and electrode gap G=3 μm. The LC material used here is DAB-1711 (Poland) whose physical properties are listed as follows: K_{11}=17.2 pN, K_{22}=8 pN, K_{33}=20.4 pN, Δn=0.247, $\Delta\varepsilon$=10.8, and γ_1= 148 mPas.

VT curves: Figure 2 shows the simulated LC directors' orientation, potential profiles and transmittance of the proposed triode DFFS at 10.8V. For FFS employing a positive LC, dead zones always appear at the center of the electrodes and gaps [17]. However, since the dead zones on both sides are well complemented, the triode DFFS mode shows relatively flat transmittance profile. And the middle bulk layers remain stationary as explained above.

Figure 3 depicts the VT curves of three cell gaps: d=10, 12 and 14 μm. The 14-μm cell shows maximum transmittance >96% at on-state voltage of 10.8V. Here, we normalize the transmittance to that of two parallel polarizers. The 10-μm and 12-μm cells show a lower transmittance because in such thin cells the reoriented upper and bottom layers would interfere and then push the middle LC layers to rotate in the voltage-on state, resulting in a lower transmittance and slower GTG response. However, the cell cannot be too thick, otherwise the GTG response would be slower since the vertical electric field is weaker and other problems such as narrow viewing angle and crosstalk would also occur. Therefore, we choose 14μm as the optimal cell gap for the chosen LC mixture. To widen the viewing angle, we use A+ plate and C- plate on each side of the cell as compensation films [18,19].

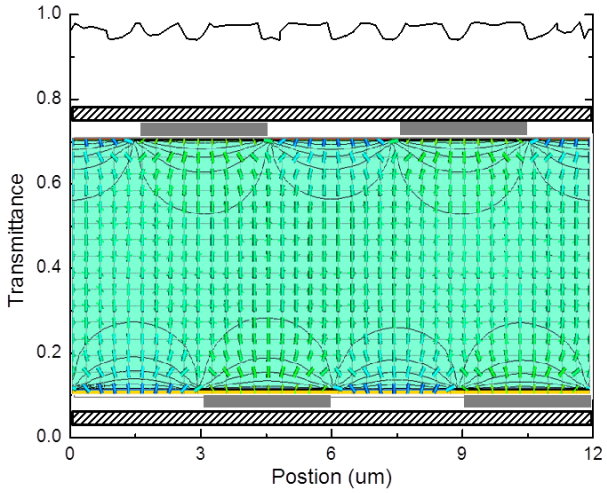

Figure 2. Transmittance (upper), electric potential (lower) profiles and LC directors' orientation (color) of the triode DFFS at a bright state (10.8V).

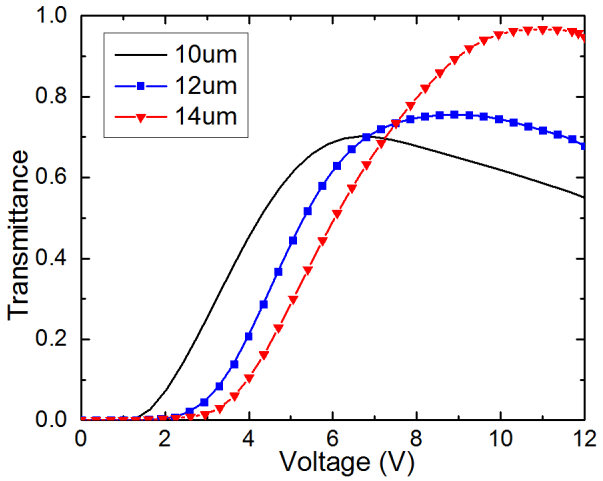

Figure 3. Simulated VT curves of the proposed triode DFFS cell with d=10 μm, 12 μm, and 14 μm at λ=550 nm.

Response Time: To evaluate the GTG response time, during calculations we divided the VT curve uniformly into eight gray levels (1-8). As usual, the response time is defined as 10%-90% transmittance change. To achieve fast GTG response time, the commonly used overdrive and undershoot voltage method [20] is also applied here. During relaxation process, a short pulse is applied to generate a vertical field to expedite the LC decay process. When the transmittance level is close to the desired final state, a bias voltage is applied to hold the transmittance.

Table 1 summarizes the calculated rise and decay times for the 14-μm cell. All the GTG response time (except the rise time from gray level 1 to 2 which is 1.29 ms) is below 1 ms. The averaged rise time of all gray levels is 739 μs and decay time is 478 μs at ~22°C. The response time can be further reduced if a lower viscosity LC material is used or higher overdrive and undershoot voltages are applied. These results are comparable to those of polymer-stabilized blue phase liquid crystals but with a lower voltage [21-23].

Table 1. Calculated GTG Response Time (Unit: ms)

	1	2	3	4	5	6	7	8
1		1.29	0.96	0.98	0.89	0.97	0.95	0.85
2	0.53		0.83	0.83	0.93	0.90	0.80	0.48
3	0.56	0.28		0.80	0.82	0.76	0.66	0.38
4	0.60	0.41	0.55		0.78	0.72	0.72	0.35
5	0.60	0.30	0.20	0.36		0.74	0.60	0.32
6	0.64	0.38	0.27	0.55	0.17		0.64	0.31
7	0.71	0.46	0.42	0.39	0.20	0.18		0.43
8	0.85	0.63	0.50	0.51	0.35	0.85	0.95	

4. Discussion

With its submillisecond GTG response time, the proposed triode DFFS mode has potential applications in color sequential displays and 3D displays. Figure 4(a) depicts the driving method for the application of triode DFFS mode for 2D display using simultaneous driving method. For decay process between gray levels, the frame time is composed of three periods: the first period is to generate vertical field, the second is for scanning row by row to input data voltage through driving TFTs, and the third period is for emission. Figure 4(b) shows the driving method for the triode DFFS in 3D displays to reduce left-right crosstalk.

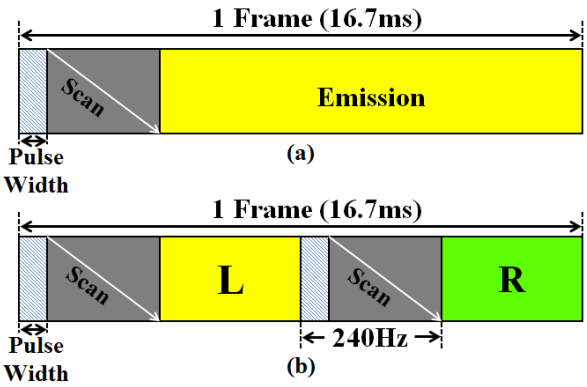

Figure 4. Display driving methods for the triode DFFS using simultaneous emission in (a) 2D and (b) 3D **display**

The major challenge of the proposed triode DFFS mode is it requires precise registration between top and bottom pixel electrodes in order to keep high transmittance. For the misalignment less than 0.5 μm, the triode DFFS mode can still achieve over 80% peak transmittance [24]. However, as misalignment increases, the dead zones on both sides are no longer well complemented, thus resulting in a decreased peak transmittance. For the worst scenario misalignment is 1.5 μm, that is the top and bottom pixel electrodes overlap perfectly, the peak transmittance drops to ~49%.

In the proposed triode DFFS mode, two TFTs are needed to control the applied voltage on top and bottom pixel electrodes in order to obtain different gray levels. The top common electrode is always connected to ground while the voltage on bottom common electrode (either 11V or 0V) can be controlled by a simple electronic circuit.

5. References

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