Three-Terminal Hybrid-aligned Nematic Liquid Crystal Cell for Fast Turn-off Switching

Jong-In Baek[**], **Ki-Han Kim**[**], **Jae Chang Kim**[*], **and Tae-Hoon Yoon**[*]

Abstract

A three-terminal hybrid-aligned nematic liquid crystal (3T-HAN LC) cell capable of fast turn-off switching is proposed in this paper. By employing the relaxation process initiated by an electric-field pulse, a fast turn-off time of less than 1 ms can be obtained through optically hidden relaxation. A low operating voltage and high transmittance were confirmed through simulations and experiments

Keywords : liquid crystal display, hybrid alignment, three-terminal electrode, fast turn-off switching

1. Introduction

Liquid crystal displays (LCDs) have been widely used owing to their low power consumption, light weight, and thinness, but they have slow response characteristics, or turn-on and turn-off times. A fast turn-on time can be obtained by employing the overdriving method [1]. The turn-off time, however, which is limited by the slow relaxation behavior of the LC, has to be improved. Several methods have been proposed to achieve fast turn-off switching [2-5], but these have demerits, such as the requirement of a bias voltage, a high operating voltage, and low transmittance.

Among the various LCD modes, the hybrid-aligned nematic liquid crystal (HAN-LC) cells have been proposed for specific purposes, such as for transflective and privacy protection displays [6-8]. To achieve a fast turn-off time for the HAN-LC cell, a three-electrode (3T) structure was proposed. The previously proposed 3T-HAN cell, however, showed a high operating voltage and low transmittance [3].

A HAN-LC cell with three electrodes that has a fast turn-off switching time of less than 1 ms is proposed in this paper. Its high transmittance and low operating voltage were confirmed through simulations and experiments.

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2. Principle and Experiment

Shown in Fig. 1 is the 3T-HAN LC cell proposed herein. The previously proposed 3T-HAN cell realized a bright state through the downward tilting of the LC, by applying a fringe field, which resulted in low transmittance due to the presence of a vertical electric field. In the 3T-HAN cell proposed herein, a fringe field is applied between the bottom grid and the bottom common electrodes to twist-deform the LCs for the turned-on bright state. Although the in-plane field is predominant only on the edges of the grid electrodes, high transmittance can be obtained because the LCs both on and between the grid electrodes can be rotated by an elastic torque [9-10].

As soon as the turn-on voltage is removed, a vertical electric-field pulse is applied between the top and bottom common electrodes, for fast turn-off switching. Then the relaxation starts from the vertically aligned state. During relaxation, the azimuthal angle of the director is parallel to the rubbing direction and to the transmission axis of the top or bottom polarizer. Consequently, the cell remains in a dark state. Since the cell shows the dark state even though the LC is under relaxation, the optical response can be much faster irrespective of the LC relaxation. Fig. 2 shows the operation principle of the proposed method schematically.

3. Results and Discussion

Numerical calculations were performed using the commercially available software LCD Master. For comparison

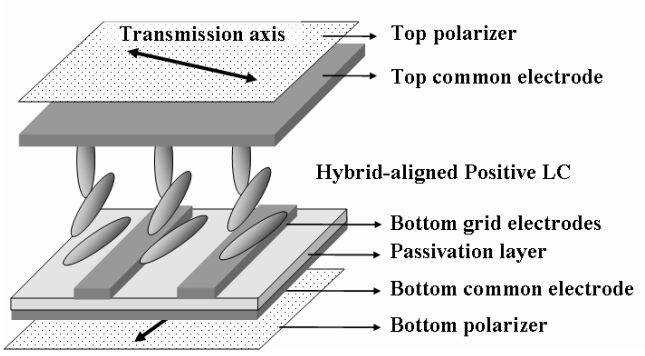


Fig. 1. Configuration of a 3T-HAN cell.

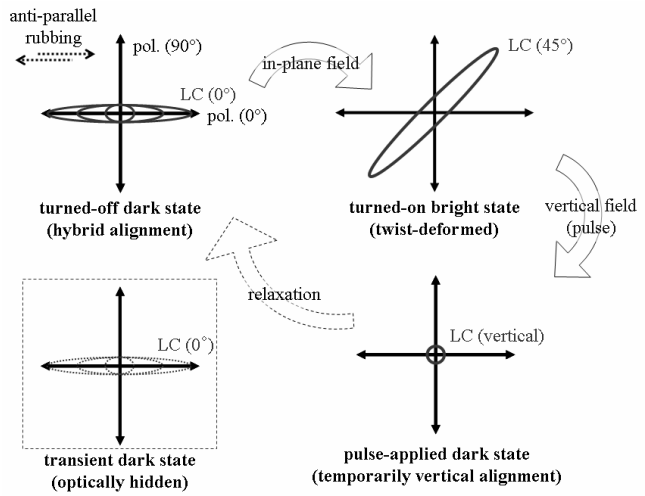
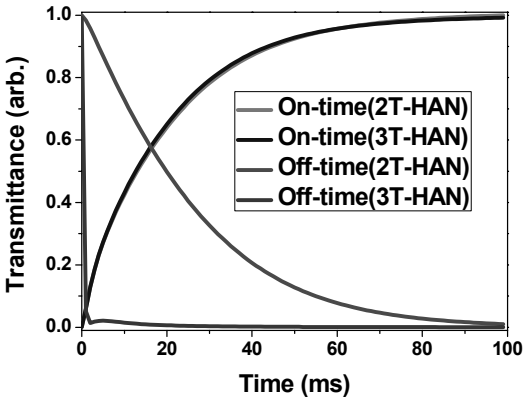


Fig. 2. Operation principle of the proposed method.

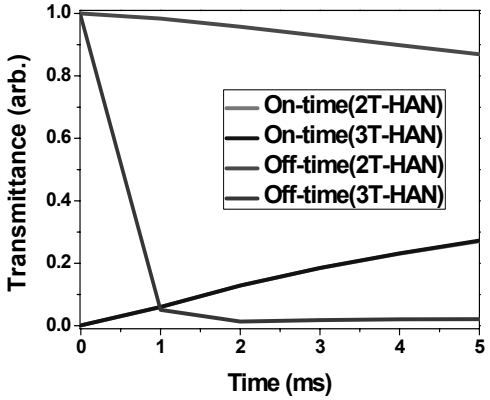
purposes, a two-electrode (2T) HAN cell without a top common electrode was also considered. In the simulation, the thicknesses of the electrodes, the passivation, and the LC layers were 300 nm, 400 nm, and 6 μm, respectively. The dielectric and optical anisotropies of the LC were 7.1 and 0.1064, respectively. The pre-tilt angles of the top and bottom substrates were 89 and 1°, respectively. The anti-parallel rubbing directions of the top and bottom substrates were parallel to the transmission axis of the bottom polarizer, which was connected to the top polarizer. The angle between the rubbing direction and the grid electrodes was 10°.

Almost the same maximum transmittances (about 27%) of both cells were obtained when 5 V with 1-kHz square pulses was applied to the 2T-HAN cell and to the 3T-HAN cell with a floated top electrode.

After the high transmittance of the proposed structure was



(a) Numerically calculated response times of the 2T- and 3T-HAN cells.

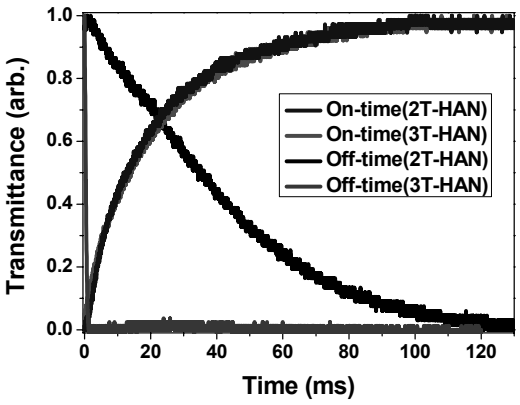


(b) Magnified graphs.

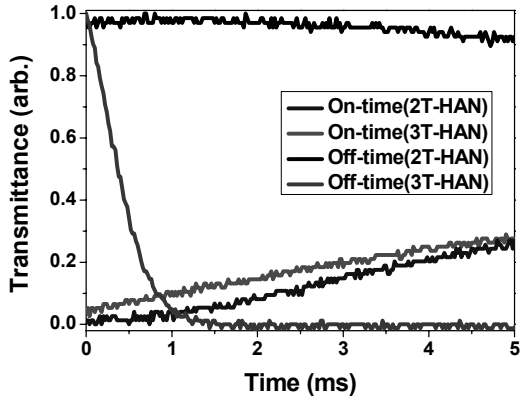
Fig. 3. Numerically calculated response times of the 2T- and 3T-HAN cells.

confirmed through the simulation, the response times were calculated. Fig. 3 shows the simulated response characteristics. The turn-on time of the 3T-HAN cell was almost the same as that of the 2T-HAN cell because the same turn-on voltage was applied to the same hybrid-aligned state. On the other hand, the turn-off time of the 3T-HAN cell with turn-off switching (< 1 ms) was much faster than that of the 2T-HAN cell or of the 3T-HAN cell without turn-off switching (≒ 50 ms). When a vertical electric-field pulse of 10 V for 1 ms was applied, the simulated turn-off time of the 3T-HAN cell became about 0.5 ms.

To confirm the proposed method experimentally, both the 2T- and 3T-HAN cells were fabricated with the same parameters that were used in the simulations. As confirmed through the simulation, the maximum transmittance of the 2T-HAN cell was almost the same as that of the 3T-HAN cell with a floated top common electrode when 4.8 V with 1-kHz square pulses was applied.



(a) Measured response times of the 2T- and 3T-HAN cells.



(b) Magnified graphs.

Fig. 4. Measured response times of the 2T- and 3T-HAN cells.

The measured response times of the fabricated samples are shown in Fig. 4. The turn-on times of both cells were the same, as confirmed through the simulations. On the other hand, the 3T-HAN cell with the vertical electric-field pulse showed a much faster turn-off time (≒ 0.6 ms) compared to the 2T-HAN cell or to the 3T-HAN cell without a vertical electric-field pulse (≒ 80 ms).

The turn-off time of the conventional LC mode predominantly depends on the elastic constants and on the viscosity of the LC. On the other hand, the turn-off time of the proposed method strongly depends on the dielectric constant and on the amplitude of the applied vertical electric-field pulse. Therefore, the turn-off time can be accelerated by applying an electric-field pulse with a high amplitude. In the experiments that were conducted in line with this study, a vertical electric-field pulse with an amplitude of 10 V was applied for turn-off switching, and a much faster turn-off time was confirmed. Although the relaxation takes longer than the optical turn-off switching, the optical turn-off switching is very fast because of the optically hidden relaxation of LC [11].

4. Summary

In summary, the fast turn-off switching of a HAN-LC cell can be achieved with the use of the 3T structure, by applying a vertical electric-field pulse for turn-off switching. Contrary to the previously proposed turn-off switching method, both high transmittance and a low operating voltage can be guaranteed by the model proposed herein. In addition to fast turn-off switching, the turn-on time can still be reduced by employing overdriving [1]. Furthermore, the 3T-HAN cell proposed herein is capable of viewing angle switching [12-13]. Thus, the proposed LCD mode can become a special candidate for a multifunctional display.

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