Dual-Mode Liquid Crystal Display Using Dual-Frequency Liquid Crystal Cell by Fringe Field Switching

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Abstract

A dual-frequency liquid crystal featuring dual-mode operation has been proposed in this paper. This dual-mode operation controlled by the fringe field switching (FFS) allows the LC to work as either dynamic or memory mode named in terms of its monostability and bistability, respectively. For our device, the dynamic mode is essentially analogous to the FFS mode, while the memory mode to the bistable π-twist nematic mode. We have experimentally evidenced the possibility of switching of two different modes simultaneously in the same device. Besides, the electro-optical effects for both modes have been demonstrated and discussed.

1. Introduction

The family of liquid crystal devices (LCDs) can be basically categorized as monostable and bistable LCDs for different purposes of use. Monostable LCDs, having only one permissive state in the absence of electric field, are primarily adopted in the battery-powered appliances such as home televisions and computer monitors where high contrast, wide viewing angle, fast response, and full color capability are demanded. Towards a rapidly growing urge for energy-saving displays like e-book, e-paper, and etc. where the images need no frequent refreshing, bistable LCDs are considered as a promising solution because the salient trait of bistable LCDs is that the image, once displayed, could be memorized for a long time, ranging from seconds up to years.

In this paper, we will present a dual-mode LCD which features a dual-frequency (DF) LC cell and the horizontal switching using the grid electrode analogous to that of the typical fringe field switching (FFS) [1]. Figure 1 schematically outlines the principle of our dual-mode LCD operation where the LC molecules can be deformed on the plane of substrate continuously from the 0-state with zero twist or off state, to the on-state by the action of a horizontal electric force generated across the grid electrode, which, as a whole, is referred to as dynamic mode operation as shown in Fig. 1(a). Apart from this monostable behavior, it also possesses an inherent bistability, as shown in Fig. 1(b) where two stable states, i.e. 0-state and 180° twist state or π-state, can be switched reciprocally, which is referred to as memory mode operation.

2. Experiment

In preparation of our DFLC cell, the material MLC-2048 (Merck KGa) is used, whose physical properties at 20°C are summarized as follows: $f_c \approx 12$ kHz, the dielectric anisotropy $\Delta\varepsilon=+3.2$ at f=1 kHz and $\Delta\varepsilon=-3.4$ at f=100 kHz, and the refractive anisotropy $\Delta n=0.2214$ at wavelength $\lambda=589.3$ nm. A portion of chiral dopant (S-811) is blended with the DFLC to produce a pitch of around 14 μm, and then this mixture is filled into an empty cell of thickness of 3.6 μm such that the d/p ratio is well adjusted near 0.25, a value for theoretically equalizing the free energies of both 0-state and π-state for the sake of a permanent bistability [2-3]. One of the cell substrates is patterned with grid electrode, the width of which and the electrode gap are in turn 4 and 6 μm, separated from the ground electrode by a thin layer of insulator, whereas, the other side is simply made of glass. On both substrates is spin-coated the planar alignment layer RN-1702 (Nissan Chemical) to strongly anchor the LC molecule at a pretilt angle of 1~2°. The LC rubbing directions on two substrates are antiparallel and set at an angle of ~7° with respect to the axis of grid electrode. Crossed polarizers, the transmission axis of one of which coincides with the axis of LC, are laminated onto each side, therefore the 0-state always corresponds to the off state or dark state in either mode.

3. Results

To validate the dynamic performance, the voltage-transmittance (V-T) curve, driven by a voltage of low frequency of 1 kHz and backlighted by a white light source (MC-961C, Photal), is plotted in Fig. 2 where the maximum brightness is obtained at 6.4 V and the contrast ratio is over 1000:1 benefiting from the perfect dark state free of any optical compensation. Similar to the conventional FFS mode, wide viewing angle could also be predicted for this device. Figure 3 shows the measured electro-optical response of the interstate transition. The 0-state is represented by a low transmittance whereas the π-state by a high transmittance between the crossed polarizers. The waveforms we designed to switch the 0-state to π-state or π-state to 0-state are the two-section pulses which consist of a voltage of 100 kHz of 70 V for 10 ms followed by a voltage of 1 kHz of 70 V for 50ms, and a voltage of 1 kHz of 70 V for 50 ms followed by a voltage of 100 kHz of 70 V for 50ms, respectively. The total transition time amounts to 287.6 ms with 0-state-to-π-state time of 206 ms and π-state-to-0-state time of 81.6 ms. In addition, the retention time of these two stable states has been found permanent as long as the d/p ratio is near 0.25 which makes this device very suitable for the low-power image storage.

Figure 4 shows the measured wavelength dispersion of transmittance by a spectrometer (MCPD-3000, Photal), where the inserted photos taken by the CCD camera (IK-637K, Toshiba) clearly display the two stable states. The 0-state appears an excellent darkness easily distinguished from the π-state with a reddish brown. For seeking a higher contrast ratio, optical compensation to the π-state can be employed.

4. Summary

In conclusion, we proposed a dual-mode operation utilizing the dual-frequency LC which is driven by the FFS. This dual-mode operation combines a dynamic mode, analogous to the FFS mode, for the application of gray scales and high contrast ratio, and a memory mode, with two stable states, for the application of image memory capability and energy-saving ability. The switching mechanism as well as the electro-optic effects has been in detail demonstrated and discussed. In the future, more works will be dedicated to the issues on the faster response time and lower driving voltage.

References

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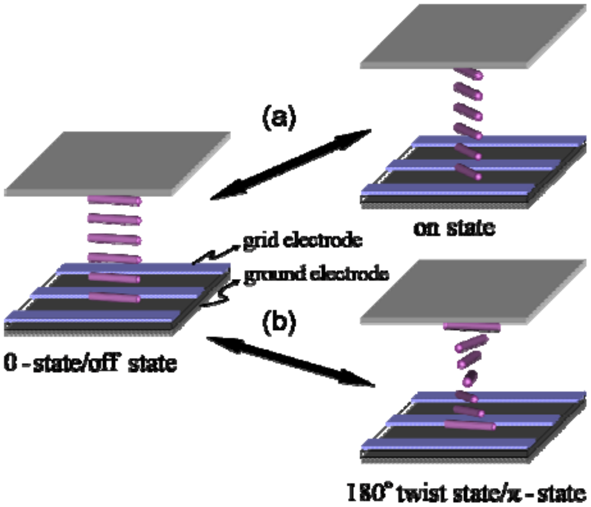

Fig. 1. Principle of dual-mode operation: (a) dynamic mode, and (b) memory mode.

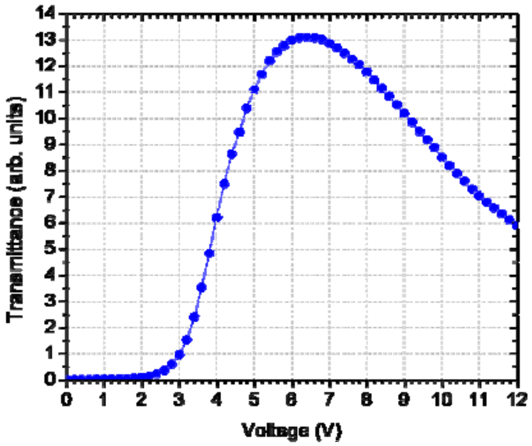

Fig. 2. Voltage-transmittance curve of dynamic mode.

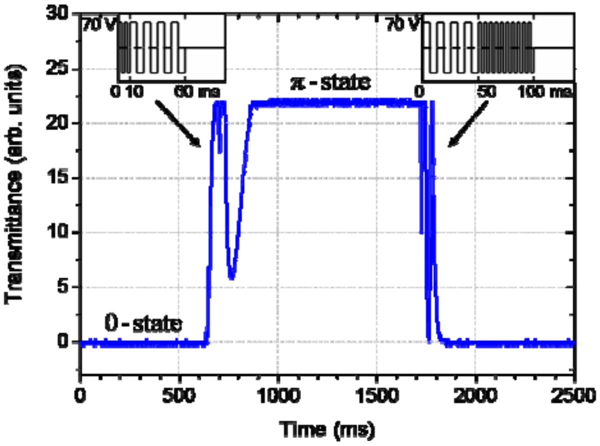

Fig. 3. Electro-optical response of memory mode.

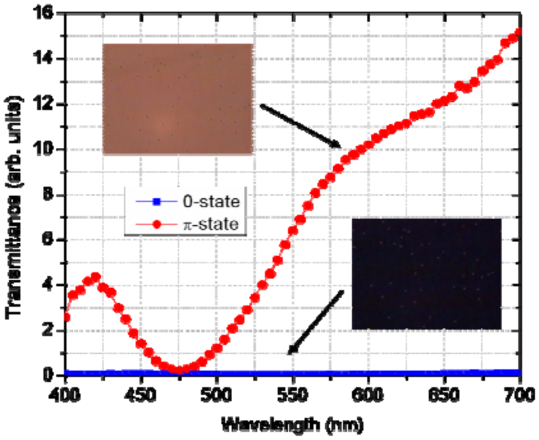

Fig. 4. Wavelength dispersion of transmittance of memory mode.