High Speed Displays Based on a Nonchiral Smectic C Liquid Crystal in an Antiparallel Planar Geometry

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Abstract

We demonstrated a high speed liquid crystal (LC) display mode based on a nonchiral smectic C LC in an antiparallel planar geometry. In this antiparallel planar nonchiral smectic C (APNSC) LC mode, analog gray scales and wide viewing properties are achieved using a stepwise thermal annealing process (STAP). Because of an initially stable LC alignment in large area through the STAP, the APNSC LC mode exhibits the characteristics of fast response and high contrast ratio. This new APNSC mode is suitable for processing the dynamic image at a video rate in the next-generation LCDs.

1. Introduction

A variety of technologies such as the multi-domain alignment [1] and the in-plane switching (IPS) mode [2] have been developed to improve the viewing angle characteristics of a liquid crystal display (LCD). However, new technologies to achieve fast electro-optic (EO) response of the LCD have not been fully established yet. Although some LCDs based on the ferroelectric LC (FLC), for example, the surface-stabilized (SS) [3] and the deformed-helix FLC modes [4], exhibit intrinsically fast switching characteristics, they suffer from poor alignment of the FLCs in large area because of the polar nature of the FLC materials [3]. Moreover, the SSFLC mode is bistable, and thus no analog gray scales are available unless a time- or space-averaging process is employed.

Recently, it has been reported that a nonchiral smectic C (NSC) LC in twisted [5,6] and transverse electrode [7] configurations show fast response suitable for dynamic applications. In contrast to the FLCDs, analog EO characteristics were achieved utilizing the dielectric anisotropy ($\Delta\varepsilon$) of the NSC LCs like the nematic case.

In this paper, we demonstrate a fast analog EO effect of the NSC LC in an antiparallel planar geometry. The antiparallel planar nonchiral smectic C (APNSC) LC mode exhibits wide viewing and fast response characteristics in the dielectric driving scheme. A stepwise thermal annealing process (STAP) is a key technology to obtain an initially stable LC alignment required for the high speed relaxation and high contrast in the APNSC LC cell.

2. Stepwise Thermal Annealing Process and Operation Principle

In order to obtain uniform alignment of the NSC LC material, a key factor is that the smectic layer structure should be precisely aligned in a large area. The conventional approach is to thermally anneal the LC cell from the isotropic phase to the smectic phase at a constant rate, which requires a huge amount of time to be processed.

Based on the fact that the formation of the smectic layer structure occurs at the nematic-smectic phase transition, we have developed the STAP process. In the STAP process, the LC cell is initially cooled down

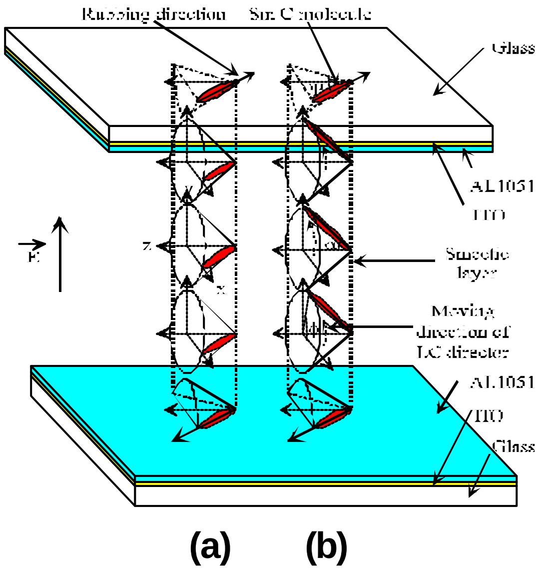

Figure 1. The operation principle of our APNSC LC cell: (a) a dark state under no electric field and (b) a bright state under an electric field.

at a rapid rate (typically order of 1 °C/min) from the isotropic phase to the nematic phase. Then, the cooling rate is abruptly decreased so that the temperature of the LC cell may be virtually maintained at the nematic-smectic transition. It has been found that the STAP process generates a stable, well-aligned smectic layer structure in a time-efficient manner.

The STAP process can be successfully applied to a simple NSC LC configuration, for example, the APNSC LC mode as shown in Fig. 1. Figure 1 shows the operation principle of the APNSC LC mode. The LC molecules with a positive dielectric anisotropy in the smectic C phase have a constant molecular tilt angle (a)?with respect to the layer normal for fixed temperature. In the absence of an external electric field (the OFF state), the molecular directors coincide with the rubbing directions on the two substrates as shown in Fig. 1(a). In this case, the APNSC LC mode is optically similar to the antiparallel planar nematic LC mode. An incident light, which is linearly polarized along the rubbing direction, is transmitted through the LC layer without experiencing any phase shift. Such transmitted light is completely blocked by the exit polarizer whose direction is perpendicular to the rubbing direction.

When an electric field is applied (the ON state), the LC molecules rotate on the induced smectic C cone. The director of the molecules tends to align parallel to the applied electric field due to the positive dielectric anisotropy and becomes to rotate away from the rubbing direction as shown in Fig. 1(b). Under this circumstance, the incident light linearly polarized along the rubbing direction experiences a phase modulation, and thus optical transmission is produced in the APNSC LC mode. Furthermore, due to the molecular rotation on the smectic C cone, i.e., the existence of the in-plane component projected onto the substrate plane, the wide viewing characteristics are naturally obtained.

3. Experimental

The APNSC LC cell was fabricated using two glass substrates coated with indium-tin-oxide (ITO) layers. Each inner surface of the substrates was coated with the Poly vinyl alcohol (PVA) alignment layers (Sigma Aldrich). The anti-parallel configuration was obtained using undirectionally rubbing the PVA alignment layers for homogeneous alignment. The cell was assembled in such way that the rubbing direction on each surface was anti-parallel to each other. The cell gap of 5μm was maintained using glass spacers.

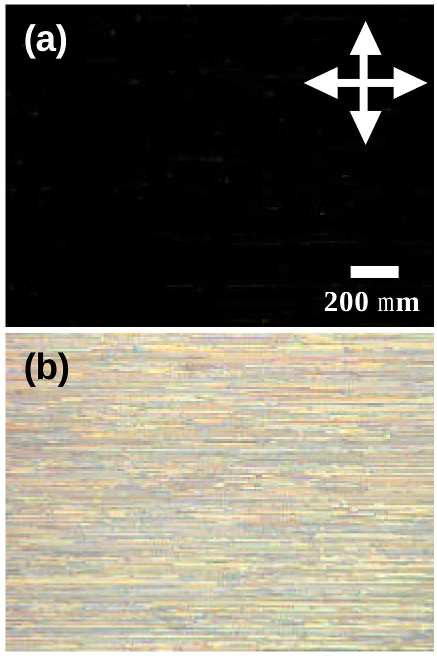

Figure 2. Microscopic observation of (a) the OFF and (b) the ON states for IS-5512 under crossed polarizers.

The APNSC LC material used in this work was IS-5512 of Merck Co. Ltd. This material has a large molecular tilt (45°) in the smectic phase with respect to the normal direction to the smectic layer and positive dielectric anisotropy ($\Delta\varepsilon$=0.49). It has the following phase sequence: isotropic → (46.2 °C) → nematic → (38.0 °C) → smectic C → (26.0 ° C) → crystal. The STAP process was applied as follows: the sample was cooled from the isotropic phase to the smectic phase at a constant rate of 1°C/min except for the transition temperature, 38.0 °C. For the initially stable alignment, the sample was kept at the transition temperature for 30 minutes.

We measured the EO transmittance, the dynamic EO response, and the viewing properties of the APNSC LC cell as a function of the voltage of a bipolar square waveform at 1 and 50 kHz, respectively. For the measurements, a He-Ne laser of 632.8 nm and a digital oscilloscope (TDS 420, Tektronix) were used. All the measurements were carried out in the smectic C phase of IS-5512.

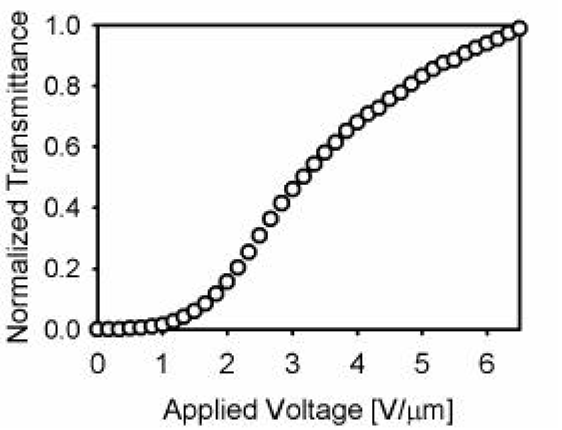

Figure 3. The EO transmitted intensities through the APNSC LC cells under crossed polarizers.

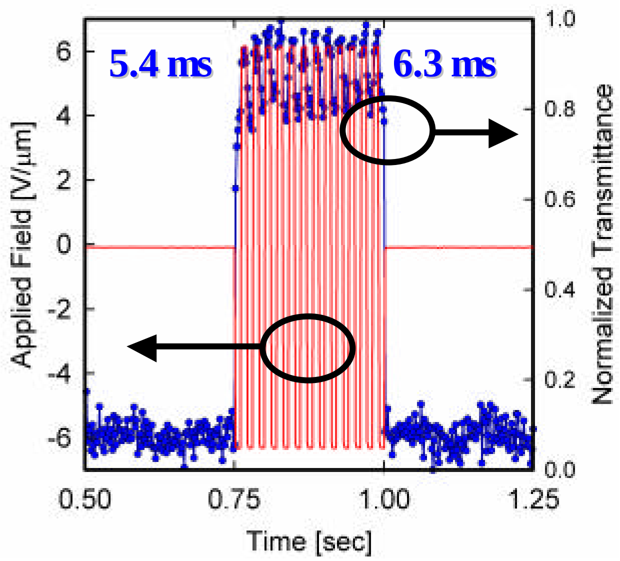

Figure 4. The dynamic EO response of our APNSC LC cell to an electric field in a bipolar square waveform.

4. Results and Discussion

Figure 2 shows the microscopic photographs of the OFF and the ON states of the APNSC LC cell under crossed polarizers, aligned by the STAP process. As shown in Fig. 2(a), in the absence of an electric field (OFF state), since the molecules are uniformly aligned parallel to the rubbing direction, no light is transmitted through the cell and thus a complete extinction is achieved. When an electric field of 6.7 V/µm is applied (ON state), the molecules experience the rotation of a (45°) on the smectic cone between two surface electrodes. For the normally incident light, the optic axis of the molecules becomes tilted by a smectic cone angle (45°) away from the plane of the substrates and thus the maximum optical transmission is obtained as shown in Fig. 2(b)

Figure 3 shows the analog gray scale capability of the APNSC LC cell as a function of the applied electric field E of a bipolar square waveform at 1kHz. With increasing the applied field above a certain threshold of 1 V/µm [8], the EO transmittance increases monotonically.

In Fig. 4, the dynamic EO response to the applied field of the square waveform of the APNSC LC cell is shown. The rising and falling times were found to be about 5.4 and 6.3 msec, respectively. One interesting point is that the falling time is comparable to the rising time in contrast to the previous NSC cases [6,7]. This may be attributed to the strain accumulated in the initially aligned state during STAP process. This switching time on the order of msec is fast enough to process the dynamic image at a video-rate.

Figure 5 shows the iso-contrast contour of the APNSC LC cell with no compensation film. Since the electric field direction is parallel to the vertical axis, whose direction is the surface normal, the LC molecular with positive dielectric anisotropy rotate parallel to the surface normal and reorient away from the rubbing direction as well as the substrate planes. Without using any compensation film, the APNSC cell shows wide and almost symmetric viewing characteristics in any direction. The contrast of 10:1 was maintained up to 60° in the range of the viewing angle measured. Due to the initially stable LC alignment, when the electric field is applied, the molecular tilt appears along the same direction. This makes the viewing properties along the vertical direction (y-axis) be somewhat wider and more symmetric than those along the horizontal direction (x-axis).

5. Conclusion

We demonstrated a new LCD mode, which has fast response, wide viewing characteristics, and analog gray scales, using the NSC LC in an anti-parallel planar geometry. Moreover, the analog optical modulation can be achieved by means of the dielectric coupling with an external electric field. Our APNSC LC mode is expected to have a great impact on production of high-performance LCDs.

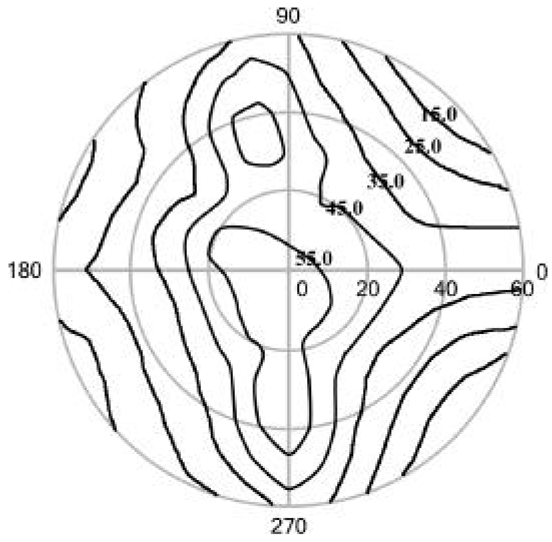

Figure 5. The iso-contrast map of the APNSC LC cell with no compensation film.

6. Acknowledgements

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7. References

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