Electro-Optic Characteristics of a Nonchiral Smectic C Liquid Crystal Display Mode in a Twisted Geometry

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Abstract

We demonstrated a fast liquid crystal (LC) display mode based on a nonchiral smectic C LC in a twisted geometry. In this twisted nonchiral smectic C (TNSC) LC mode, the analog gray scales and wide viewing properties are achieved. The continuous gray scales in the TNSC LC mode are obtained in a dielectrically driving scheme as those in the nematic mode.

1. Introduction

A variety of fast modes using ferroelectric liquid crystals (FLCs) such as surface-stabilized (SS) and deformed-helix structures [1, 2] have been extensively studied to achieve the dynamic image at a video-rate in large liquid crystal displays (LCDs). For FLCs, however, it is difficult to obtain uniform alignment in large area because of the polar nature of the FLC molecules [1]. Moreover, in case of the SSFLC mode, it shows no gray scale capability due to the intrinsic bistability unless a time- or space-averaging process is employed. Thus, in order to obtain a continuous electro-optic effect from FLCs while retaining the fast switching time, a twisted structure of the FLC was suggested [3].

Recently, a twisted structure [4] based on a nonchiral smectic C (NSC) LC has been theoretically studied and a transverse electrode structure [5] with the NSC LC layer has been experimentally studied to explore the probability of practical applications. However, an NSC LC in a twisted geometry has not been *experimentally* studied so far although its great significance for practical applications. Thus, the experimental demonstration of the twisted NSC structure will provide future display devices with enhanced properties. Moreover, unlike the display mode using FLC materials, TNSC LC mode has the analog optical modulation by means of the dielectric anisotropy ($\Delta\varepsilon$) like the nematic LC mode.

In this work, we experimentally demonstrated an

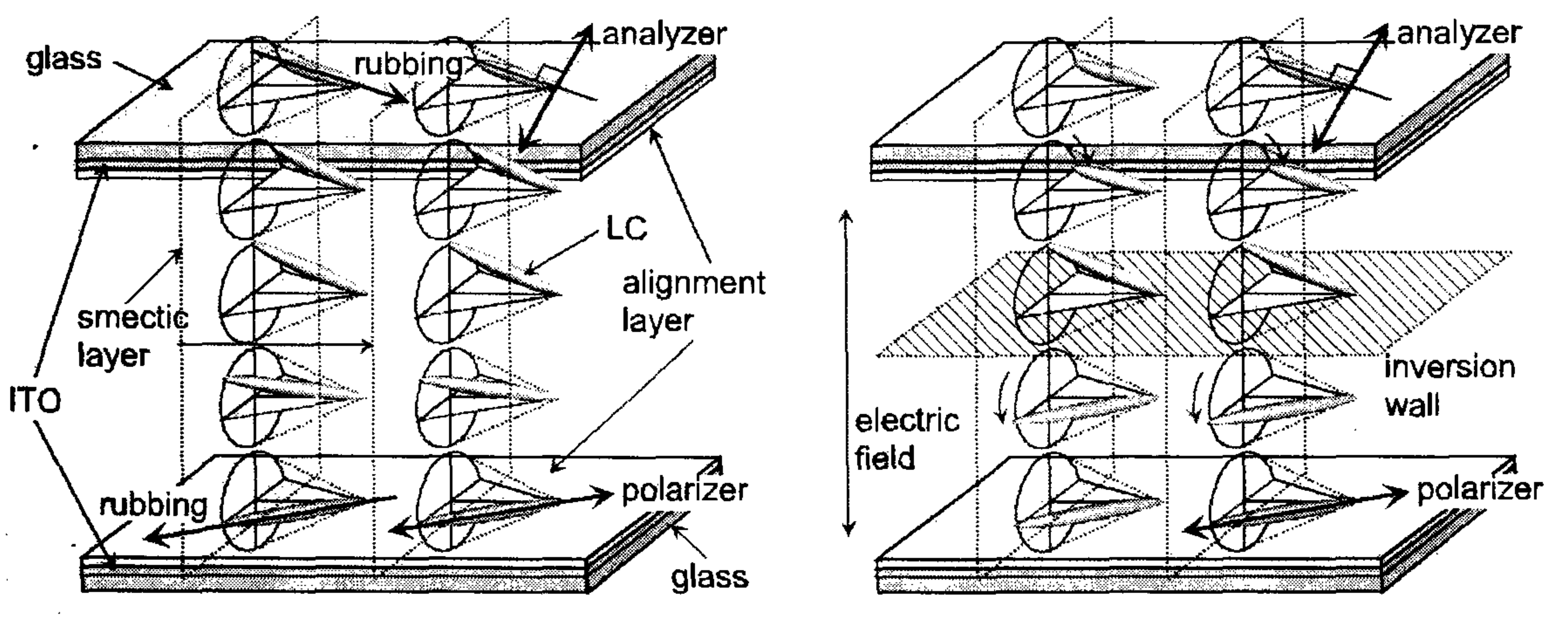

Figure 1. The operation principle of the TNSC LC mode. (a) In the absence of an external electric field, dark state is achieved. (b) when an external field is applied, bright state is obtained.

analog EO effect of the NSC LC mode in a twisted geometry. The TNSC LC mode exhibits wide viewing as well as fast response characteristics without any additional complex processes. Furthermore, using a dielectrically driving scheme, analog gray scales are easily achieved.

2. Operation Principle

Fig. 1 shows the operation principle of our TNSC LC mode with negative dielectric anisotropy $\Delta\varepsilon$. As shown in Fig. 1(a), in the absence of an external field, the external twisted angle between the easy axes on the two substrates should be equal to or less than twice of the molecular tilt of the smectic C (SmC) phase.

In the absence of an external electric field (OFF state) as shown in Fig. 1(a), the directors of the NS C LC molecules coincide with the rubbing direction on both treated substrates and are continuously twisted similar to the conventional twist nematic case. This twisted structure appears optically similar to the TN because the optical eigenmodes of the sample cell are linearly polarized when $\Delta nd \gg \lambda$, where Δn is the birefringence and λ is the wavelength of the incident light. An incident linearly polarized light whose polarization is parallel to the rubbing direction of one of the substrates is continuously reoriented as in a conventional twisted nematic LC mode. Then, the light through the LC layer is completely blocked by the analyzer whose direction is normal to the rubbing direction of the other substrate.

When an electric field is applied (ON state), the NSC LC molecules rotate along the SmC cone. The director of the molecules tends to align perpendicular to the applied electric field because of the negative dielectric anisotropy. As shown in Fig. 1(b), in the upper region, the director of the molecules rotates parallel to the rubbing direction on the top substrate. On the other hand, the director rotates parallel to the rubbing direction on the bottom substrate in the lower region. Such director rotation is energetically favored since the cone structure is restricted by the tilt angle. This type of the distortions produces an inversion wall in the middle of the cell. In these circumstances, when a linearly polarized light is incident parallel to the rubbing direction of one of the two substrates, a phase modulation is achieved and thus the optical transmission is produced.

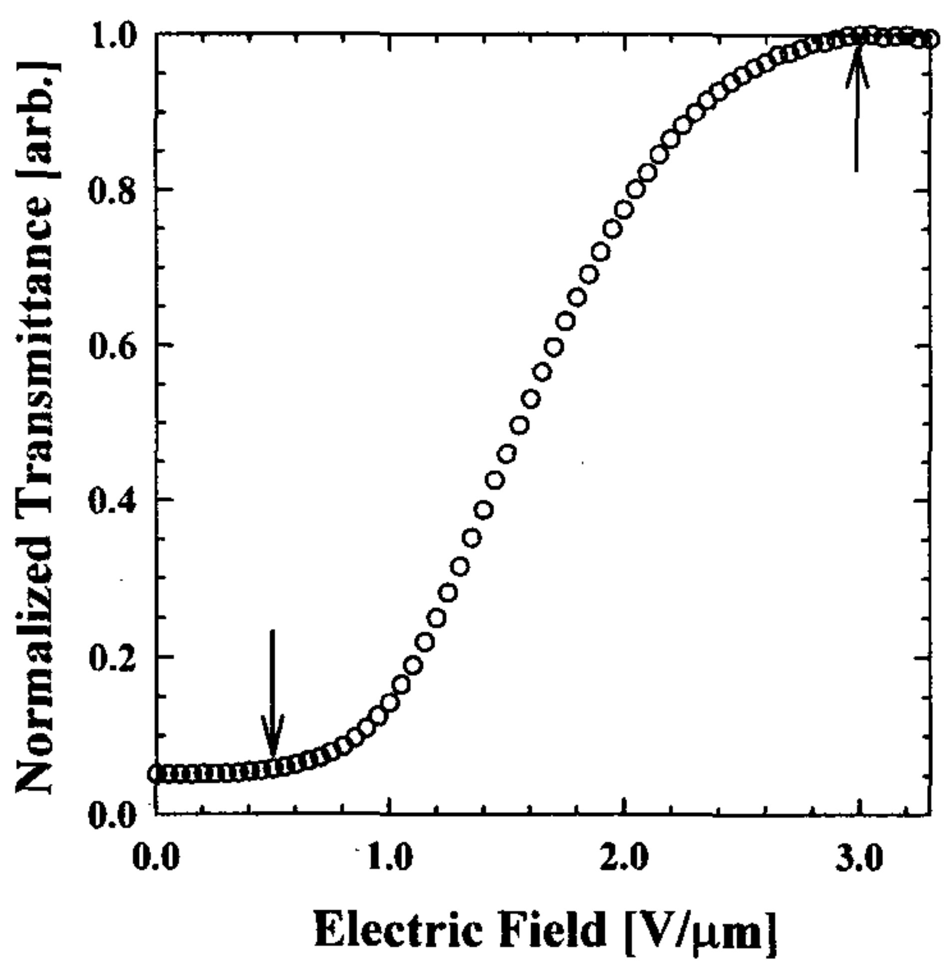

Figure 2. The EO transmitted intensities through the TNSC LC cells under crossed polarizers.

3. Experimental

The NSC LC cell was fabricated using two glass substrates, which were coated with indium-tin-oxide (ITO) layers. The alignment layer of AL1051 (Japan Synthetic Bubber Co., Japan) was coated on the inner surface of the substrates and rubbed unidirectionally to produce homogeneous alignment. The cell was maintained using glass spacers of 10μm thick. The cell was assembled in such way that the rubbing direction on the one surface was twisted to the other by 2ϕ where ϕ is the molecular tilt of the SmC state. Note that the rubbing directions on the two substrates were 45° twisted to each other.

The NSC LC material used in this work was SCE 13R of the British Drug House. This material has a large molecular tilt (≈ 22°) and negative dielectric anisotropy ($\Delta\varepsilon$ = -0.50), showing a continuous EO modulation in the 45° twisted geometry. The phase transition sequence is as follows: isotropic (>100.8 °C) → cholesteric (>86.3 °C) → smectic A (>60.8 °C) → smectic C (>-20 °C) → smectic I (< -20 °C).

Using our TNSC LC cell, we measured the EO transmittance and the dynamic response using bipolar square waveforms at 30 Hz and 50 Hz, respectively. For the measurements, a He-Ne laser of 543 nm and a digitizing oscilloscope (TDS420, Tektronix) were used. All the measurements were made at room temperature.

4. Results and Discussion

In Fig. 2, the analog gray scale capability of the TNSC LC cell was shown as a function of the applied electric field E. The EO transmittance increases monotonically with the electric field

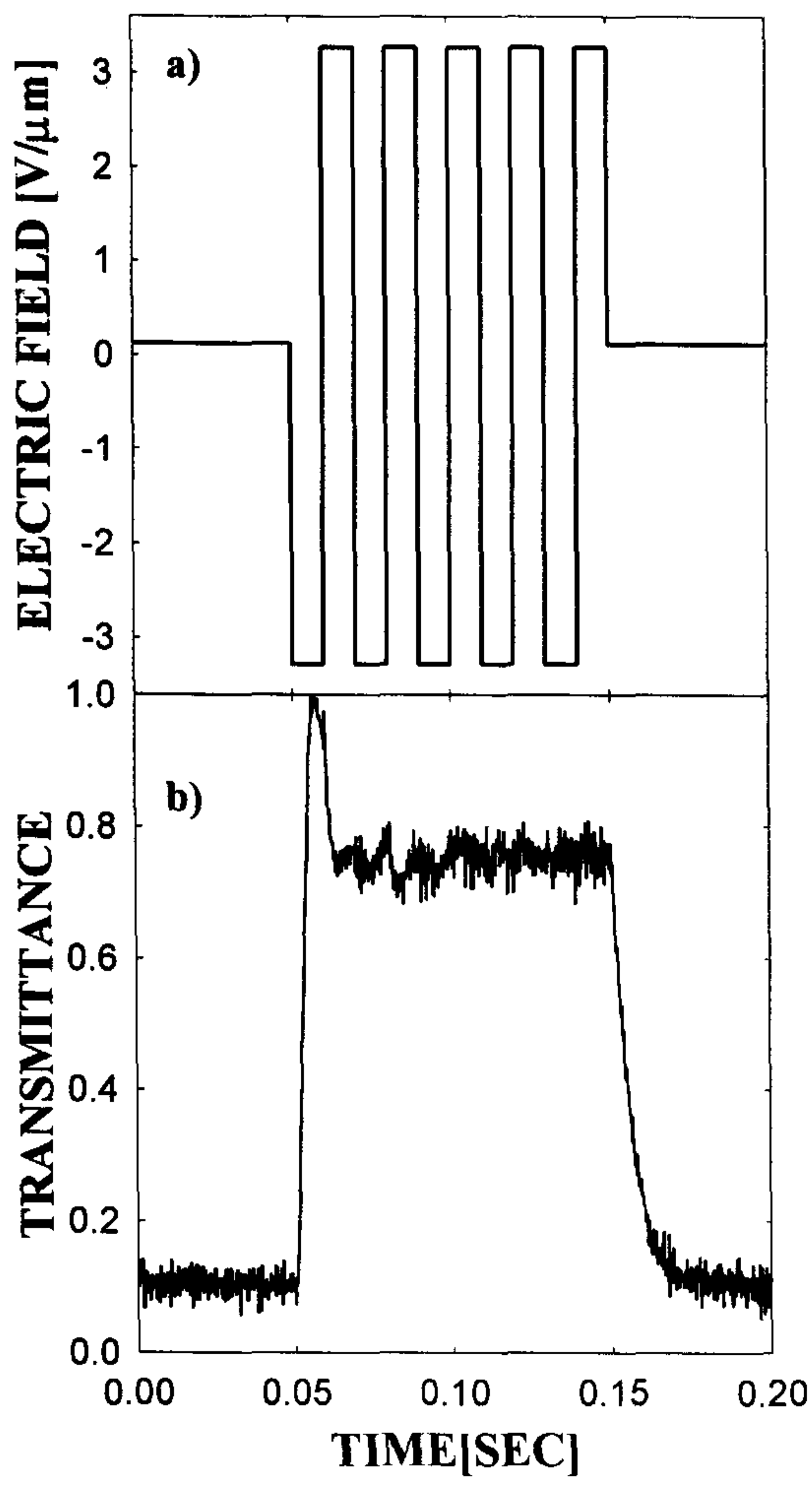

Figure 3. The dynamic EO response of TNSC LC cell to the electric field of a bipolar square waveform. a) applied electric field and b) normalized transmittance.

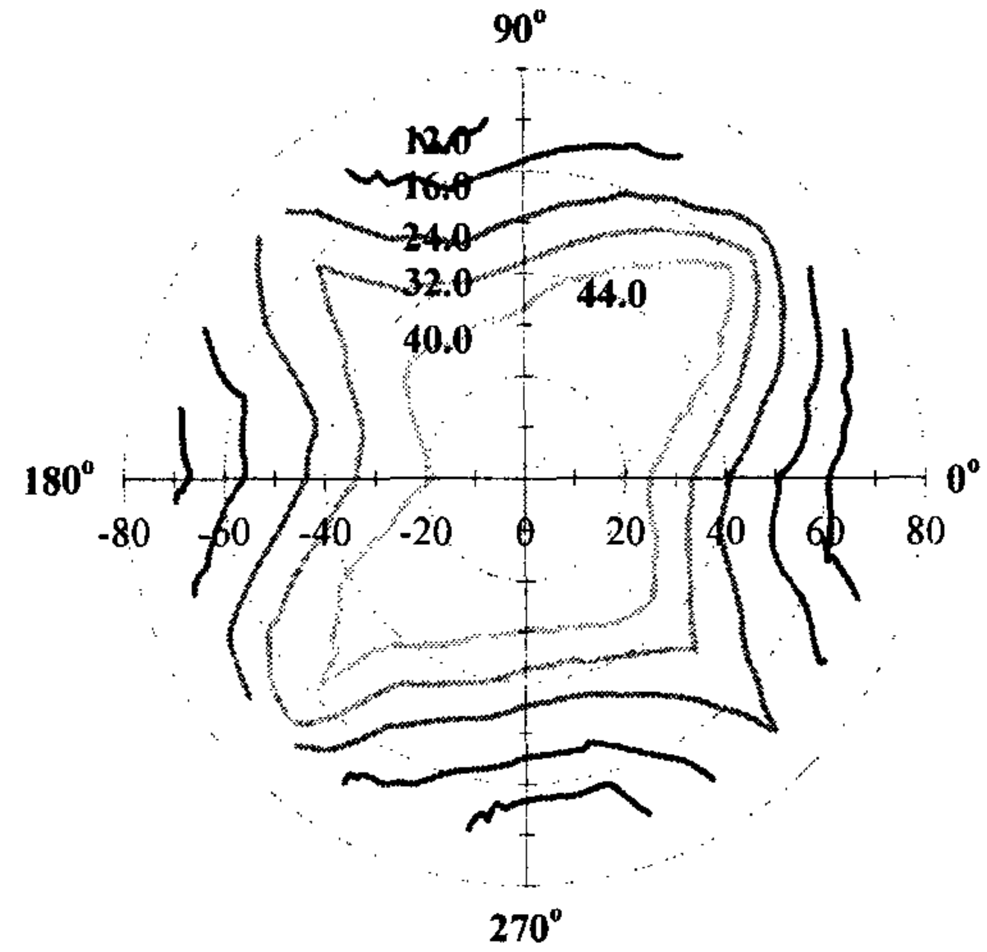

Figure 4. The iso-contrast map of TNSC LC cell

above a certain threshold [6] of 0.5 V/μm. Starting at about E = 1.0 V/μm, almost a linear relationship between the EO transmittance and E is obtained. The ON state was obtained at about 3.0V/μm. The analog EO effect of the TNSC LC is caused by the molecular rotation on an induced cone under an external electric field like that of the SmC* LC.

In Fig. 3, the dynamic EO response of the TNSC LC cell was measured using the applied field of the square wave. The rising and falling times were 2.64 and 11.28 msecs, respectively. This switching time on the order of 10 msecs is fast enough to achieve the dynamic image at a video-rate.

Figure 4 shows the iso-contrast map of the TNSC LC cell with no compensation film. Since the electric field direction is parallel to the vertical axis, whose direction is the surface normal, the molecular tilt appears along the layer normal direction and perpendicular to the surface normal. Thus, our TNSC LC cell is similar to the SSFLC mode in the ON state except for the existence of the inversion wall. As expected, the iso-contrast contour of our TNSC LC cell shows wide viewing characteristics. Without using any compensating film, the TNSC cell shows wide and symmetric viewing characteristics in any direction. No contrast inversion was observed up to 70° in the range of the viewing angle.

5. Conclusion

We demonstrated experimentally a new TNSC LC mode. As predicted in our previous work [5], the fast EO effect and wide viewing properties with analog gray scales were achieved in our TNSC LC mode using a dielectrically driving scheme. Our TNSC LC mode is expected to provide a viable technology to produce next-generation LCDs suitable for processing the dynamic image at a video rate.

6. Acknowledgement

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7. References

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