Wide-Viewing Display Configuration of Heilix-Deformed Ferroelectric Liquid Crystals

Ju Hyun Lee, *Member*, Doo Hwan You, *Student Member*, Jae Hong Park *Student Member*, Sin Doo Lee, *Member* and Chang Jae Yu

Abstract

We propose on a novel vertical configuration (VC) for a helix-deformed ferroelectric liquid crystal (HDFLC) display that has fast response, high contrast, analog gray scale capability, and wide-viewing characteristics. In contrast to a conventional HDFLC in a planar geometry, smectic layers arrange themselves parallel to the substrates, and thus, extremely uniform alignment of molecules in large area is naturally achieved in our new configuration without additional processes such as the rubbing and/or electric field treatment. Moreover, with a proper design of electrode patterns on the same substrate, multi-domain switching is easily realized without employing any complex process of alignment. Our new VC-HDFLC is expected to provide a viable technology to produce a next-generation large area LCD suitable for processing the dynamic image at a video-rate.

Keywords : Ferroelectric liquid crystal, LCD, helix deformation

1. Introduction

Recently, a variety of technologies such as multi-domain alignment [1] and in-plane switching (IPS) mode [2] have been developed to improve viewing characteristics of nematic liquid crystal displays (LCDs). Except for the IPS mode, additional complex processes for alignment are often involved in such technologies. Moreover, since the dynamic response of the nematic LC is limited by the dielectric anisotropy, a search for a new fast mode is of great importance for achieving the dynamic image at a video-rate in large LCDs.

Tilted chiral smectic, ferroelectric liquid crystals (FLCs) have been attracting considerable attention because of fast molecular switching in smectic layers, resulting from a direct coupling of the spontaneous polarization with an external electric field. Using FLCs, a surface-stabilized (SS) structure [3] and a deformed-helix structure [4] were reported previously. In both cases, it is difficult to obtain uniform alignment in large area since delicate interfacial interactions between a treated substrate and the polar nature of the FLC molecules produce zigzag defects [3] and/or stripe domains. In addition, SSFLC is bistable, and thus, no intrinsic gray scales are available unless a time- or space-averaging process is employed.

In this work, we report on a novel vertical configuration (VC) for a helix-deformed ferroelectric liquid crystal (HDFLC) display that has fast response, high contrast, analog gray scale capability, and wide-viewing characteristics. In contrast to the conventional HDFLC in a planar geometry, smectic layers arrange themselves parallel to the substrates, and thus extremely uniform alignment of molecules in large area is naturally achieved in our new configuration without additional processes such as the rubbing and/or electric field treatment.

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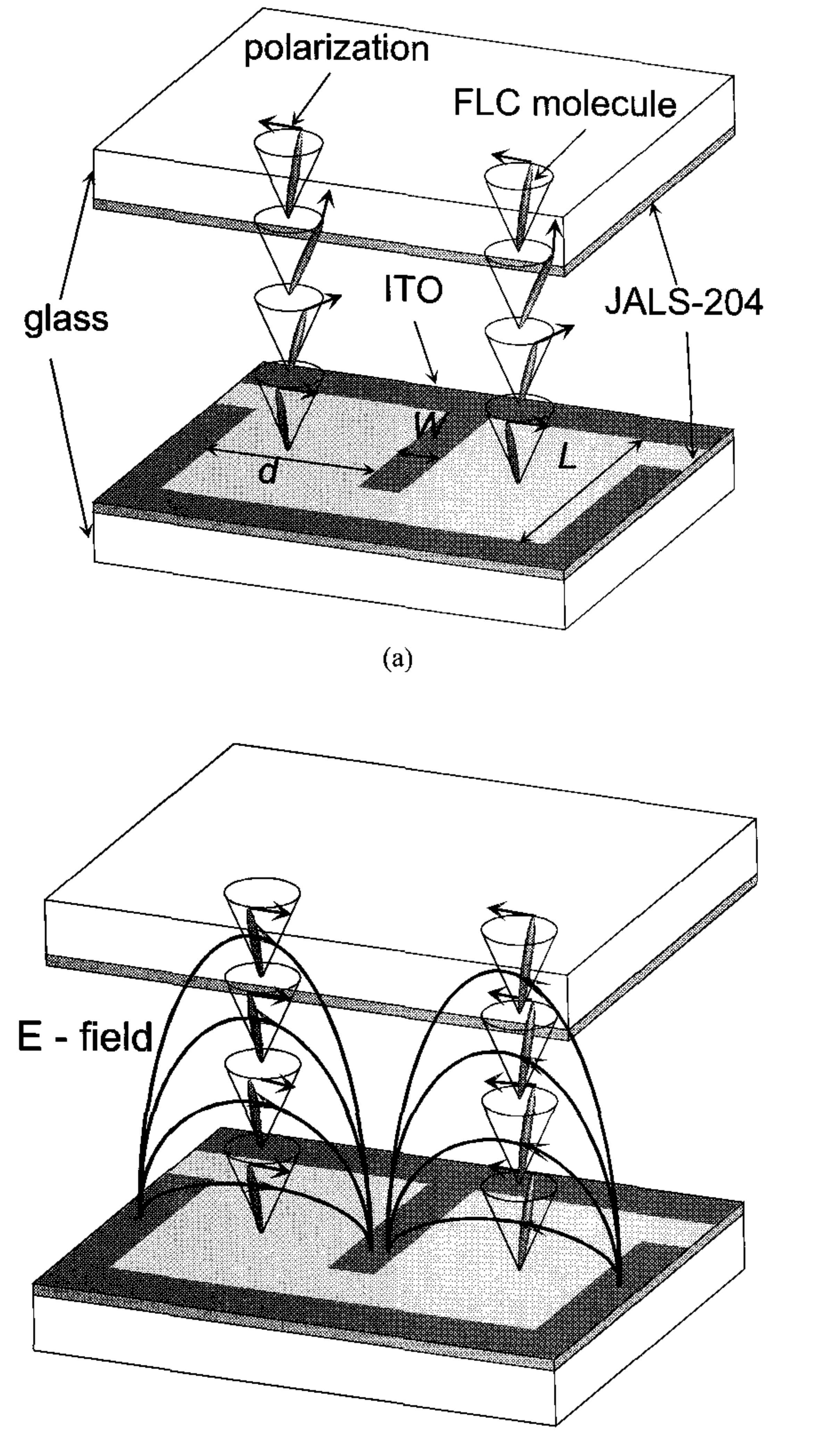
2. Theory

Fig. 1 shows the operation principle of our VC-



(a)

(b)

Fig. 1. The operation principle of two domain VC-HDFLC; (a) E = 0 and (b) E ≠ 0.

HDFLC mode. In Fig. 1(a), the average optic axis is parallel to the helix because the helical pitch is shorter than the wavelength of visible light. This situation corresponds exactly to a homeotropically aligned nematic structure, and therefore a complete extinction is obtained under crossed polarizers. On the other hand, as shown in the Fig. 1(b), when an electric field is applied, the molecules rotate in the opposite direction on the smectic C* (SmC*) cone according to the polarity of the electric field in the two subpixels, respectively. In this configuration, the average optic axes of two subpixels are combined in such a way that the average optic axis of the whole pixel is symmetric with respect to the inner electrode. The optic axis becomes continuously tilted away from the surface normal and reaches the maximum value of the SmC* tilt angle as the electric field increases.

3. Experiment

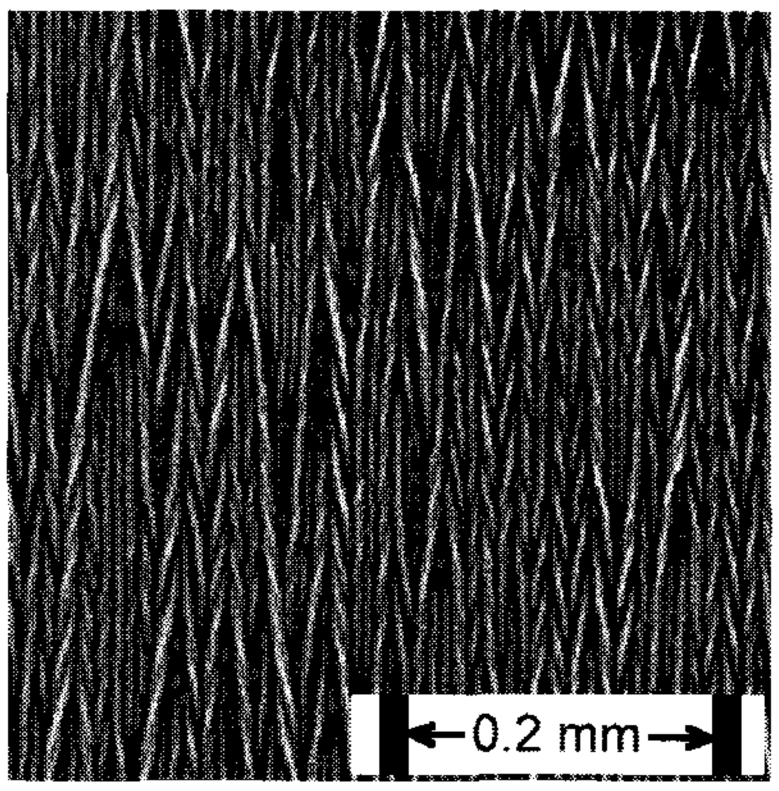
To confirm the above, we made the VC-HDFLC cell using glass substrate, only one of which has an indium-tin-oxide (ITO) layer. Parallel electrodes separated by about 50 μm, were made on the ITO layer. The polyimide (PI) layer of JALS-204 (Japan Synthetic Rubber Co.) was prepared on the two substrates to promote vertical alignment. It should be noted that no rubbing process was carried out. The cell thickness was maintained using glass spacers of 3.5 μm. The FLC material used in this work is FLC 10817 of Rolic Ltd. The phase transition sequence is as follows: isotropic → (64.5 ~ 62.4°C) → cholesteric → (62.4 ~ 61.5°C) → smectic C*. The spontaneous polarization, the tilt angle, and the helical pitch of FLC 10817 are 115 nC/cm^2, 34°, and less than 0.2 μm, respectively.

Fig. 2 shows microscopic textures of a conventional planar aligned HDFLC and our new VC-HDFLC. The planar HDFLC cell shows stripe domains caused by the surface interaction between FLC molecules and alignment layers. However, for the VC-HDFLC cell under crossed polarizers, a completely dark state is naturally obtained which gives excellent contrast. This is because in our VC-HDFLC, the helicoidal structure with a tight pitch has the average optic axis perpendicular to the cell surface and it behaves as an optically isotropic medium.

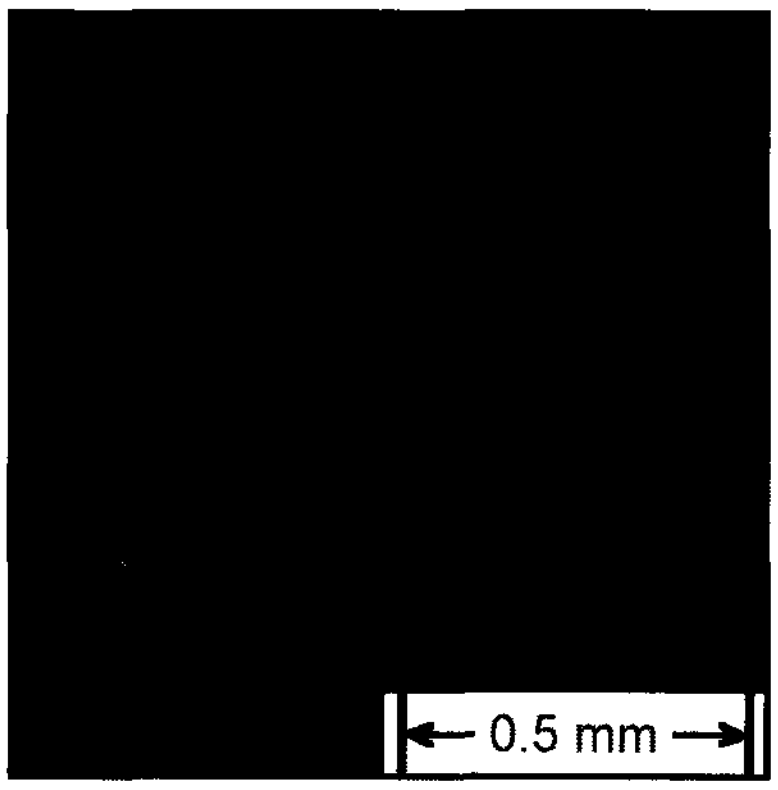
Under an operating signal of a bipolar square waveform of 1 kHz, we observed the operating texture of our VC-HDFLC cell and measured the EO transmittance, dynamic response, and viewing characteristics. For the measurements of the EO transmittance and dynamic response, a He-Ne laser of 632.8 nm and a digitizing oscilloscope (TDS420, Tektronix) were used. The cell was placed between crossed polarizers which were oriented to make angles of ±45° with respect to the electric field direction. All measurements were carried out at room temperature.

4. Results and Discussion

Figs. 3 (a) and (b) show microscopic photographs of the ON and OFF states of our VC-HDFLC cell,

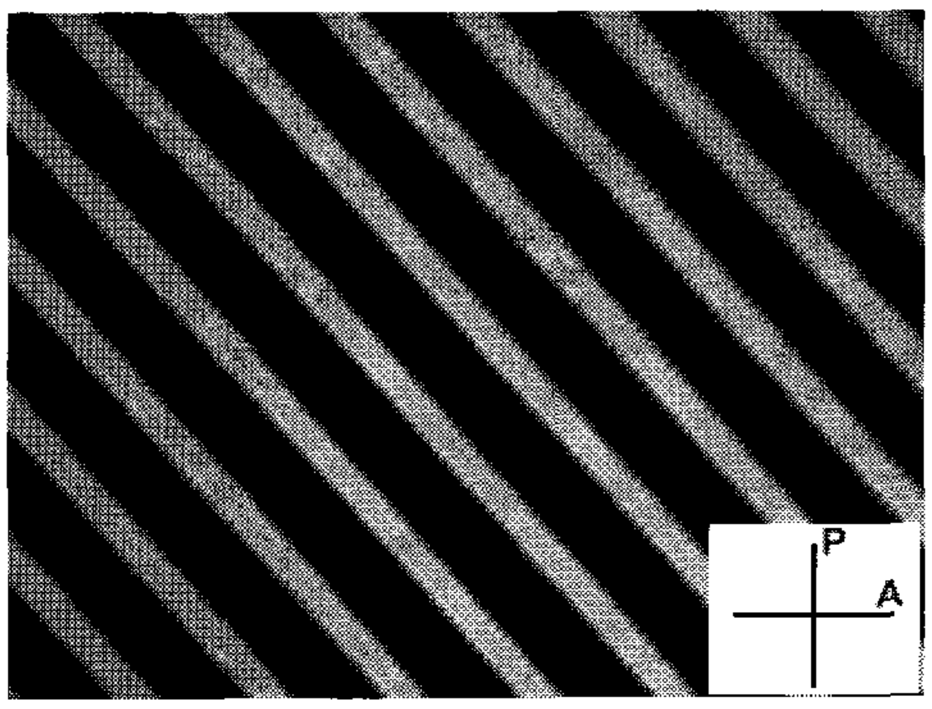


(a)

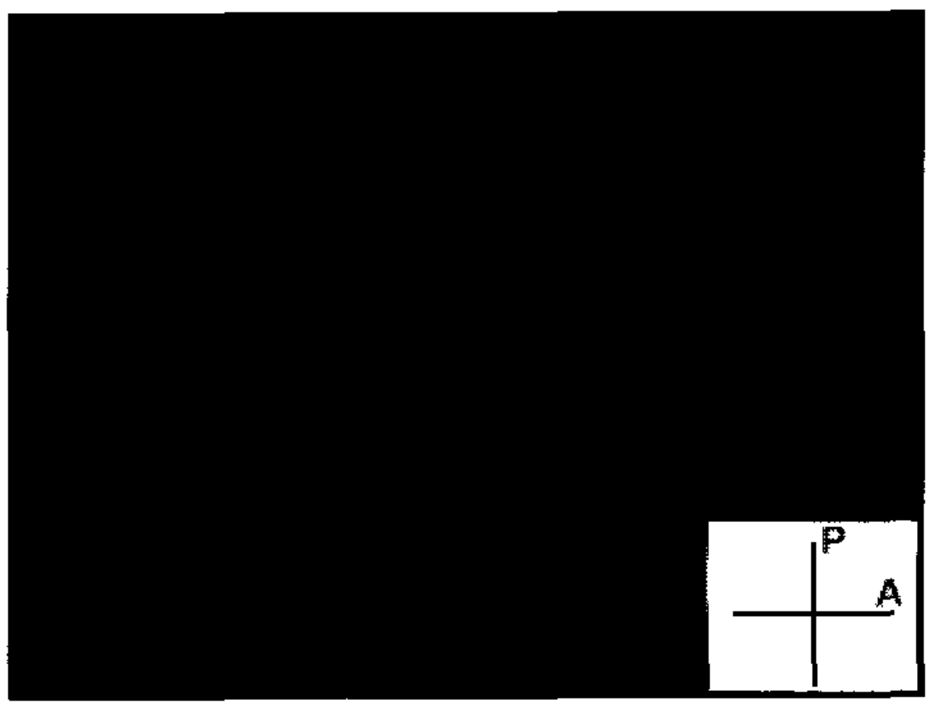


(b)

Fig. 2. Alignment textures of (a) planar HDFLC and (b) VC -HDFLC



(a)



(b)

Fig. 3. Microscopic photographs of (a) the ON and (b) the OFF states of th VC-HDFLC cell.

respectively. The gap between two inter-digital electrodes is about 50 μm. In-plane electrodes were made by etching the ITO layer to be an oppositely overlapped comb pattern. The ON state was obtained below 1.2 V/μm.

We measured the EO properties of our VC-HDFLC cell under crossed polarizers. In the absence of an electric field, no light can be transmitted through the cell and thus excellent contrast can be achieved. The active area becomes bright with continuously increasing the electric field.

In Fig. 4, the analog gray scale capability of the VC-HDFLC cell is shown as a function of the applied electric field **E**. The EO transmittance increases monotonically with increasing electric field to above 0.3 V/μm, giving the analog gray scale more capability. Starting at about **E**=0.8V/μm, a nearly linear relationship between the EO transmittance and **E** is obtained.

Fig. 5 shows the dynamic EO response of the VC-HDFLC cell to the applied electric field. The rising and falling times were about 140 and 40 μsecs, respectively. This switching time on the order of 100 μsecs was fast enougth to achieve the dynamic image at a video-rate.

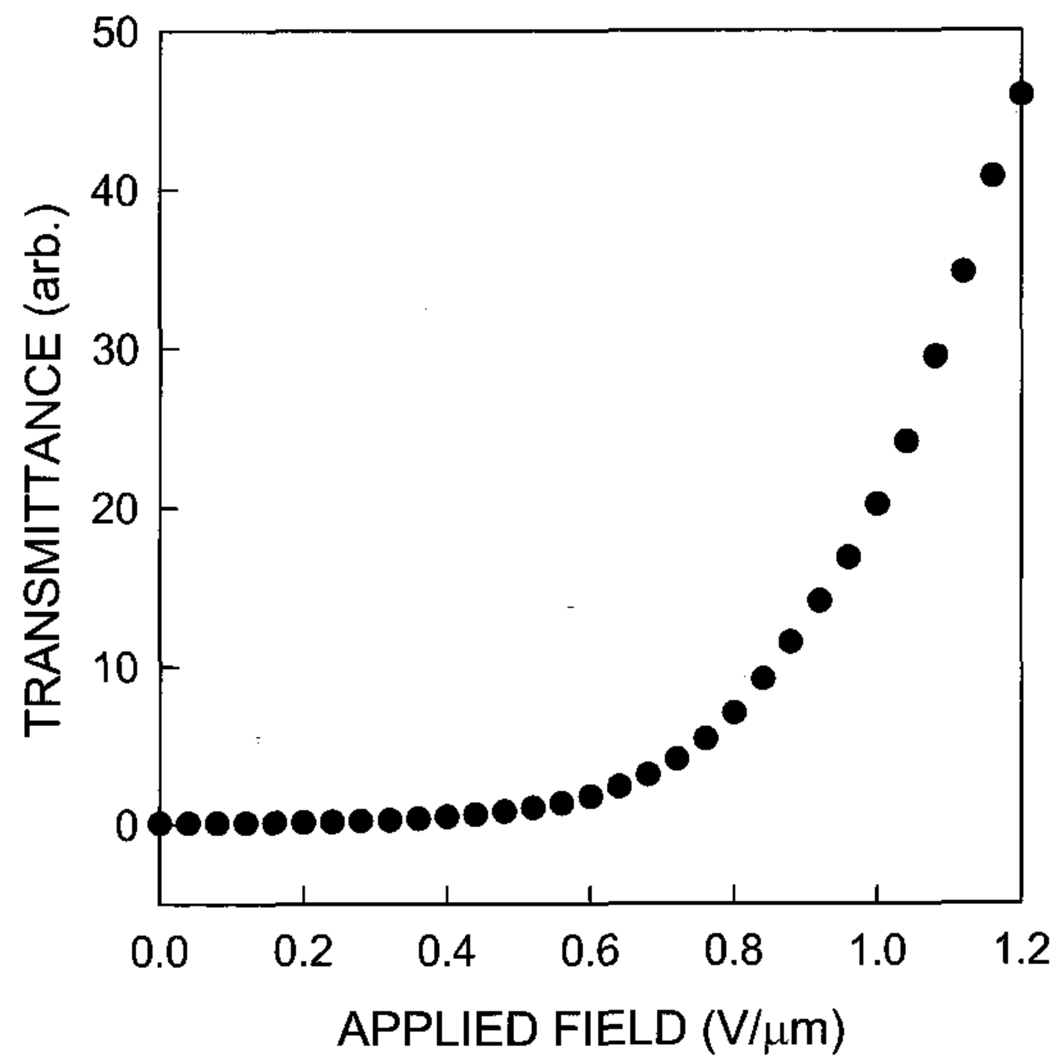


Fig. 4. The EO transmittance through the VC-HDFLC cell under crossed polarizers.

Next, we observed the viewing characteristics of the VC-HDFLC cell. Figs. 6(a) and 6(b) show the iso-

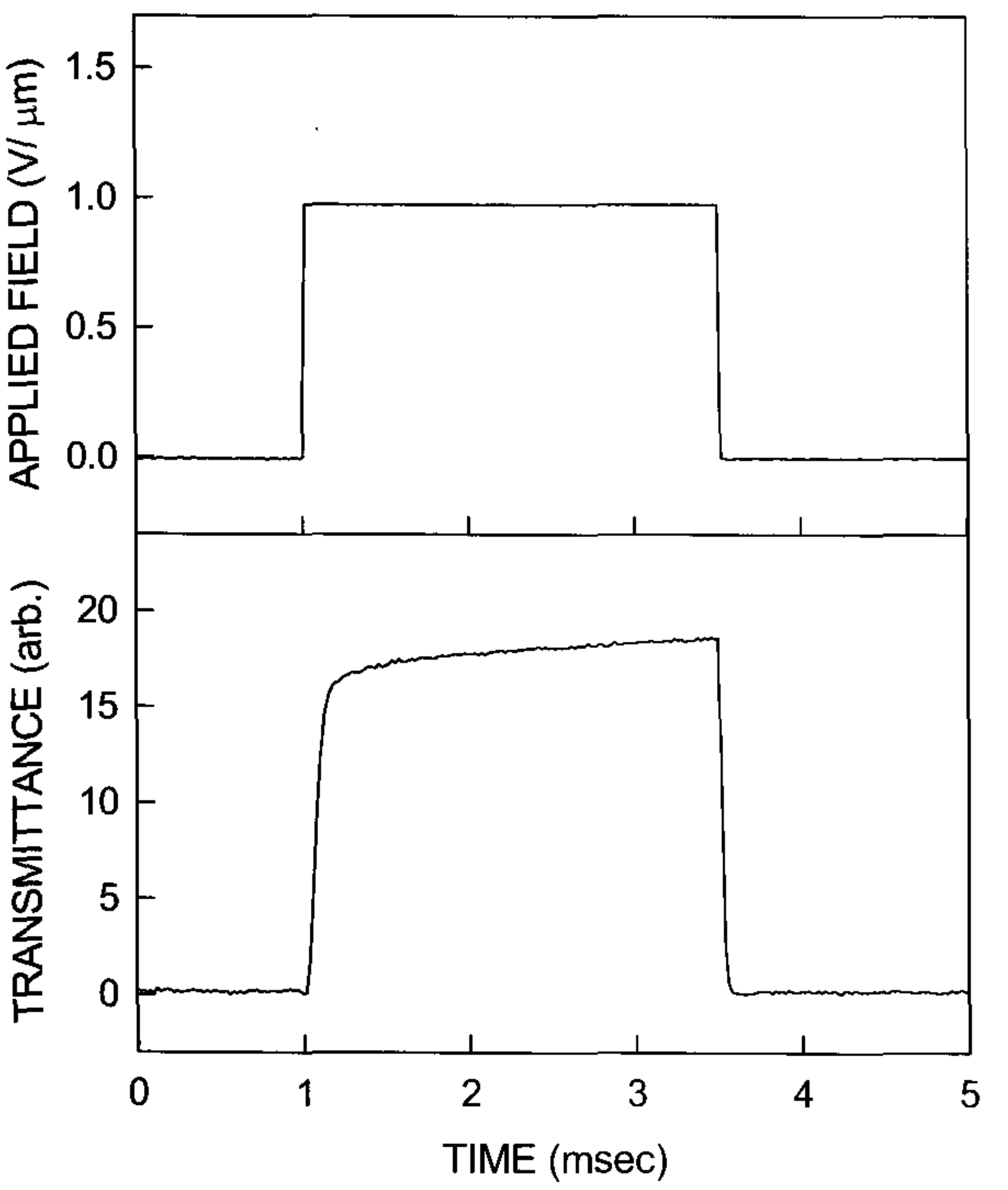


Fig. 5. The dynamic EO response of VC-HDFLC cell to the electric field of a unipolar square waveform.

contrast contours of our VC-HDFLC cell with and without a birefringence compensation of normal direction by using negative retardation films of 273 nm, respectively. The in-plane electrode direction was parallel to the horizontal axis (the x-axis). Since the electric field direction was parallel to the vertical axis (the y-axis), the molecular tilt appears along the x-axis was smaller than the y-axis. As expected, the iso-contrast contour with two-fold symmetry was obtained in our 2-domain VC-HDFLC cell. For different arrangement of in-plane electrodes, a different symmetry will be obtained. Moreover, the use of a negative uniaxial retardation film whose optic axis is perpendicular to the cell surface would enhance the viewing angle in any direction. In Fig. 6(b), no contrast inversion was clearly observable up to 70° in the range of the viewing angle that we measured. A proper design of electrode patterns such as 4-domain type and the optimum magnitude of the optical compensation will improve the viewing characteristics of VC-HDFLC cell.

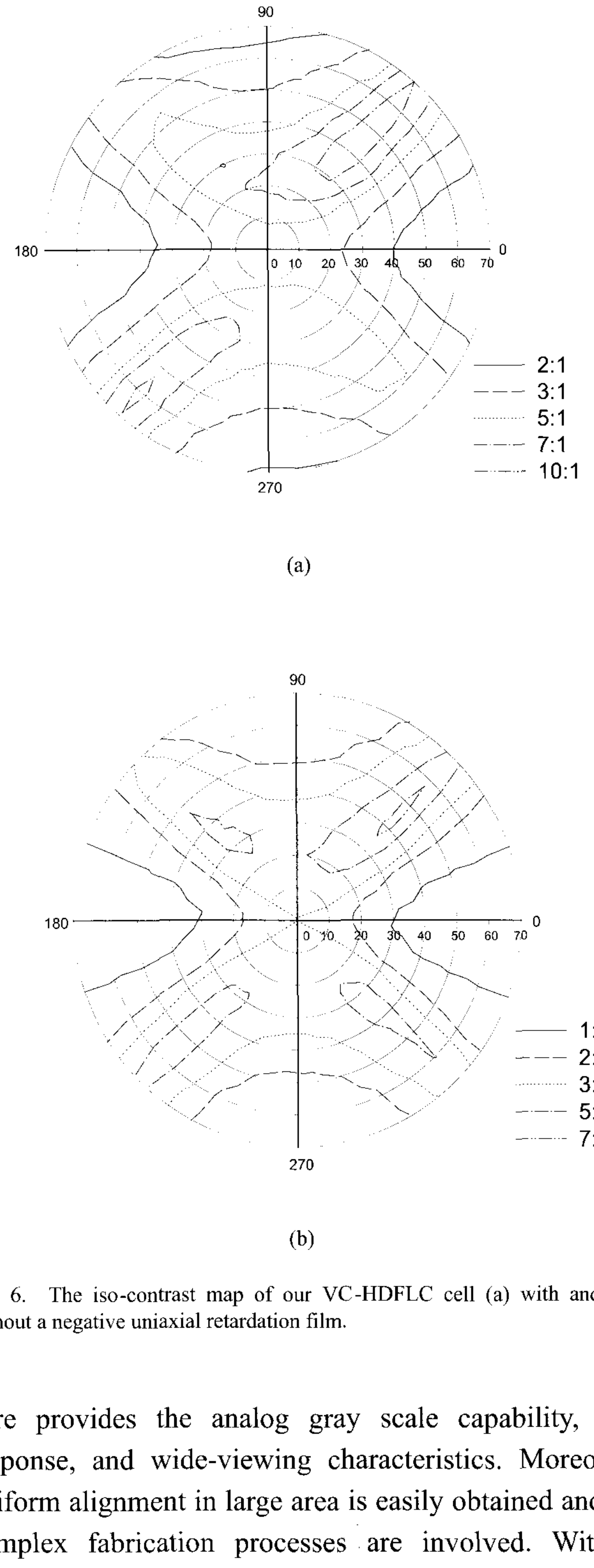


Fig. 6. The iso-contrast map of our VC-HDFLC cell (a) with and (b) without a negative uniaxial retardation film.

5. Conclusion

In summary, the new VC-HDFLC mode presented here provides the analog gray scale capability, fast response, and wide-viewing characteristics. Moreover, uniform alignment in large area is easily obtained and no complex fabrication processes are involved. With a proper design of electrode patterns on only one substrate, the polar nature of FLCs allows for a natural multi-domain structure without any additional process. Our new VC-HDFLC is expected to provide enough brightness if optimum material is used and provide a viable technology to produce a next-generation large area LCD suitable for processing the dynamic image at a video-rate.

Reference

[1] J. Chen and P. J. Bos M. Schadt, "Simple four-domain twisted nematic liquid crystal display," Appl. Phys. Lett., vol. 67, p. 1990, 1995.

[2] M. Oh-e and K. Kondo, "Electro-optical characteristics and switching behavior of in-plane switching mode," Appl. Phys. Lett., vol. 67, p. 3895, 1995.

[3] N. A. Clark and S. T. Lagerwall, "Submicrosecond bistable electro-optic switching in liquid crystals," Appl. Phys. Lett., vol. 36, p. 899, 1980.

[4] L. A. Beresnev, L. M. Blinov, D. I. Dergachev and S. B. Kondratev, "Electroopic effect in a ferroelectric liquid crystal with a small helix pitch and a large spontaneous polarization," JETP Lett., vol. 46, p. 413, 1987.