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

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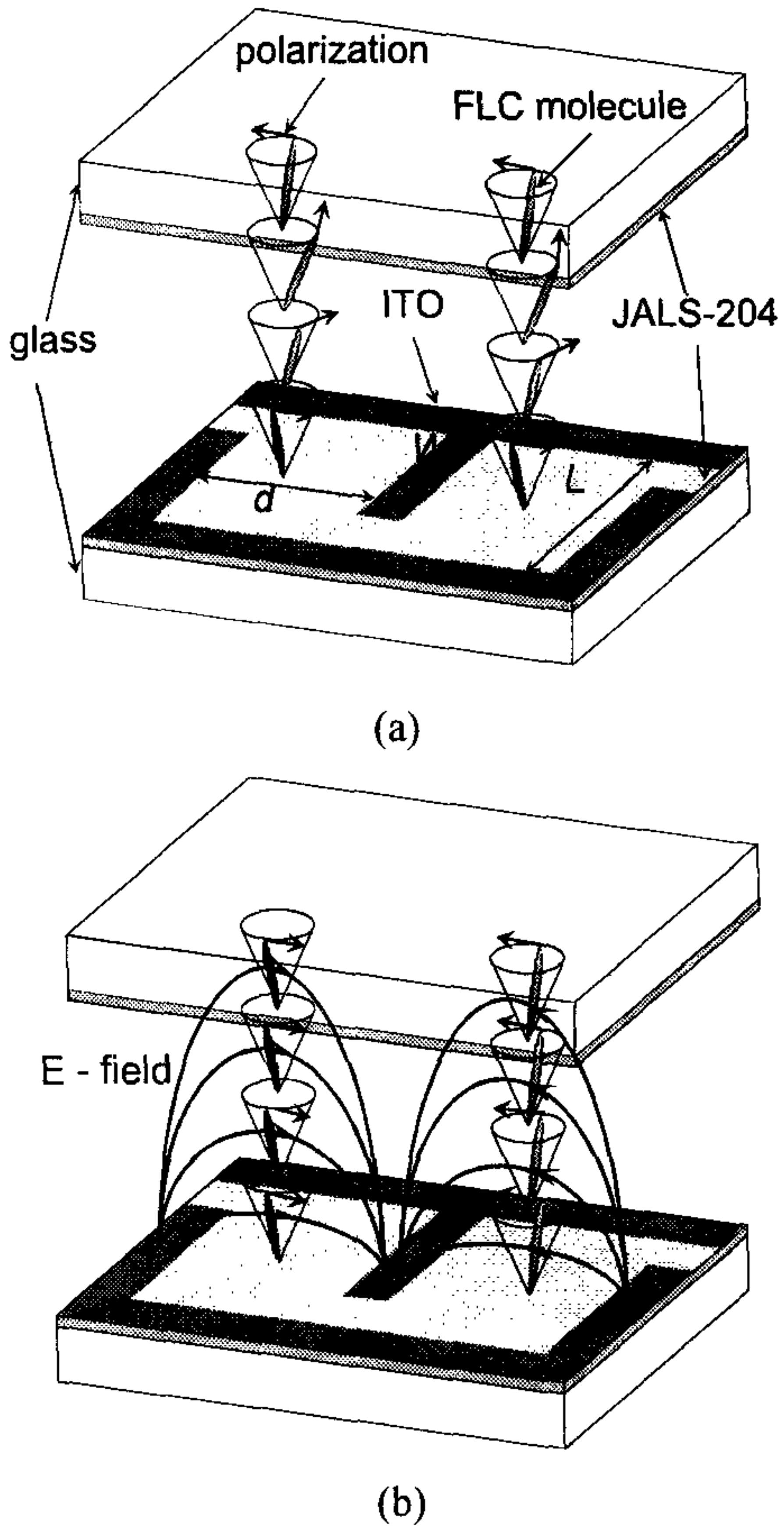
Recently, a variety of technologies such as multi-domain alignment [1] and in-plane switching (IPS) mode [2] have been developed to improve viewing characteristics of nematic liquid crystal displays (LCDs). Except for the IPS mode, additional complex processes for alignment are often involved in such 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 to achieve the dynamic image at a video-rate in large LCDs.

Tilted chiral smectic, ferroelectric liquid crystals (FLCs) have been attracted 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 which 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.

Fig. 1 shows the operation principle of our VC-HDFLC mode. In the 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 oppositely 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.

To confirm the above idea, we made the VC-HDFLC cell which was made 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.



(a)

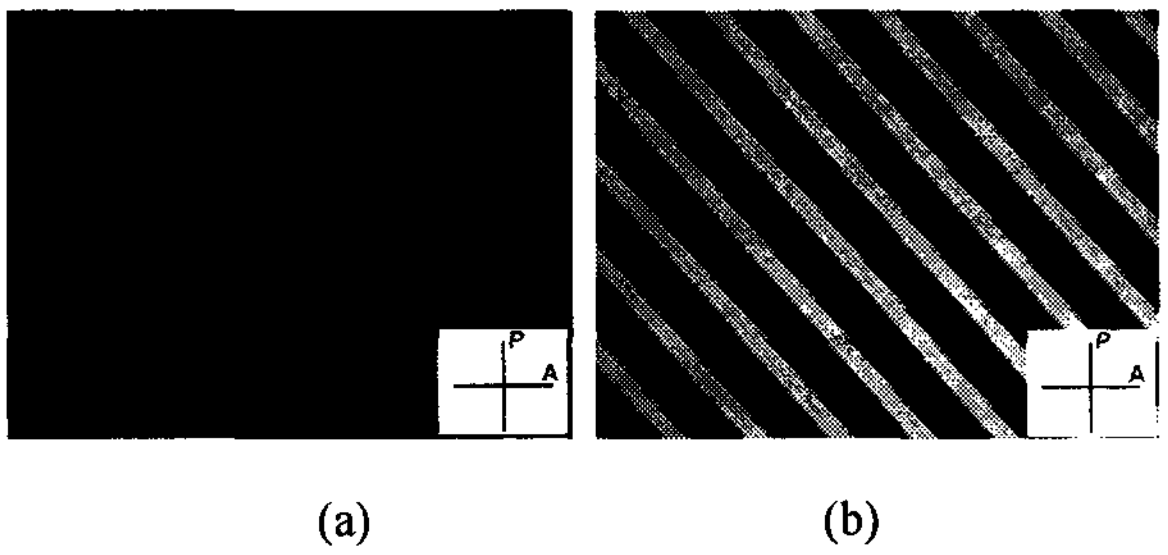
(b)

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

We compared the microscopic texture of our new VC-HDFLC with that of a conventional planar aligned HDFLC using optical microscope. The planar HDFLC cell shows typical stripe domains caused by the surface interaction between FLC molecules and alignment layers. However, for the VC-HDFLC cell, 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 and dynamic response. 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.

Figs. 2 (a) and (b) show microscopic photographs of the OFF and ON states of our 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 in an oppositely overlapped comb pattern. The ON state was obtained below 1.2 V/μm.



(a) (b)

Fig. 2. Microscopic photographs of (a) the OFF and (b) the ON states of the VC-HDFLC cell.

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. 3 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 the electric field above 0.3 V/μm, giving the analog gray scale capability. Starting at about **E** = 0.8 V/μm, a nearly linear relationship between the EO transmittance and **E** is obtained.

Fig. 4 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 is fast enough to achieve the dynamic image at a video-rate.

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-DHFLC 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.

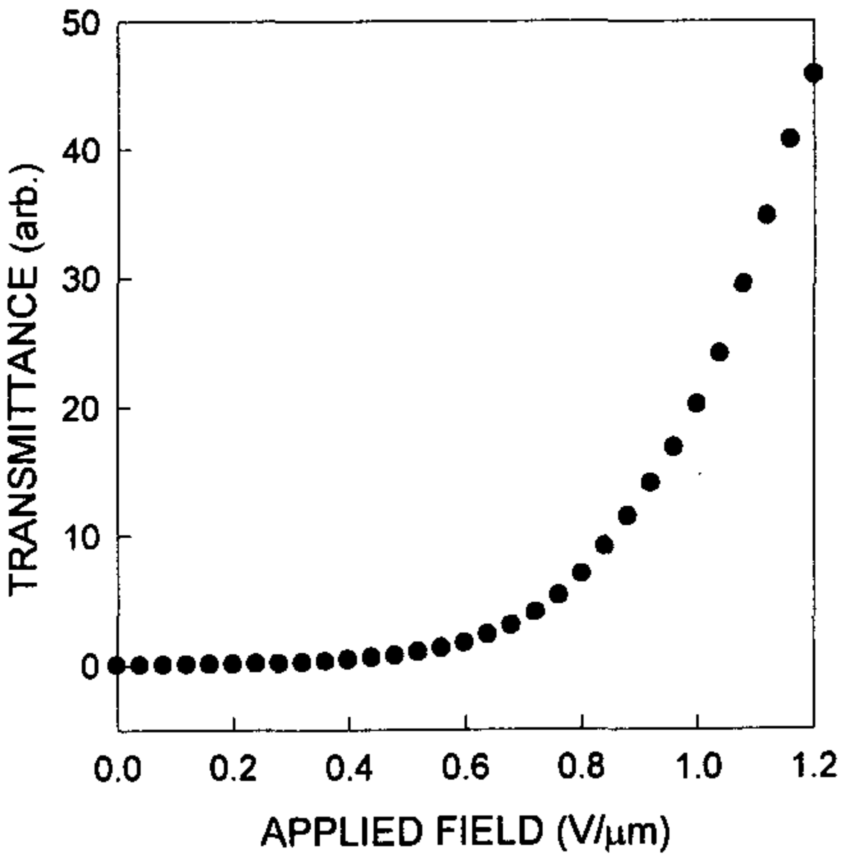


Fig. 3. The EO transmittance through the VC-DHFLC cell under crossed polarizers.

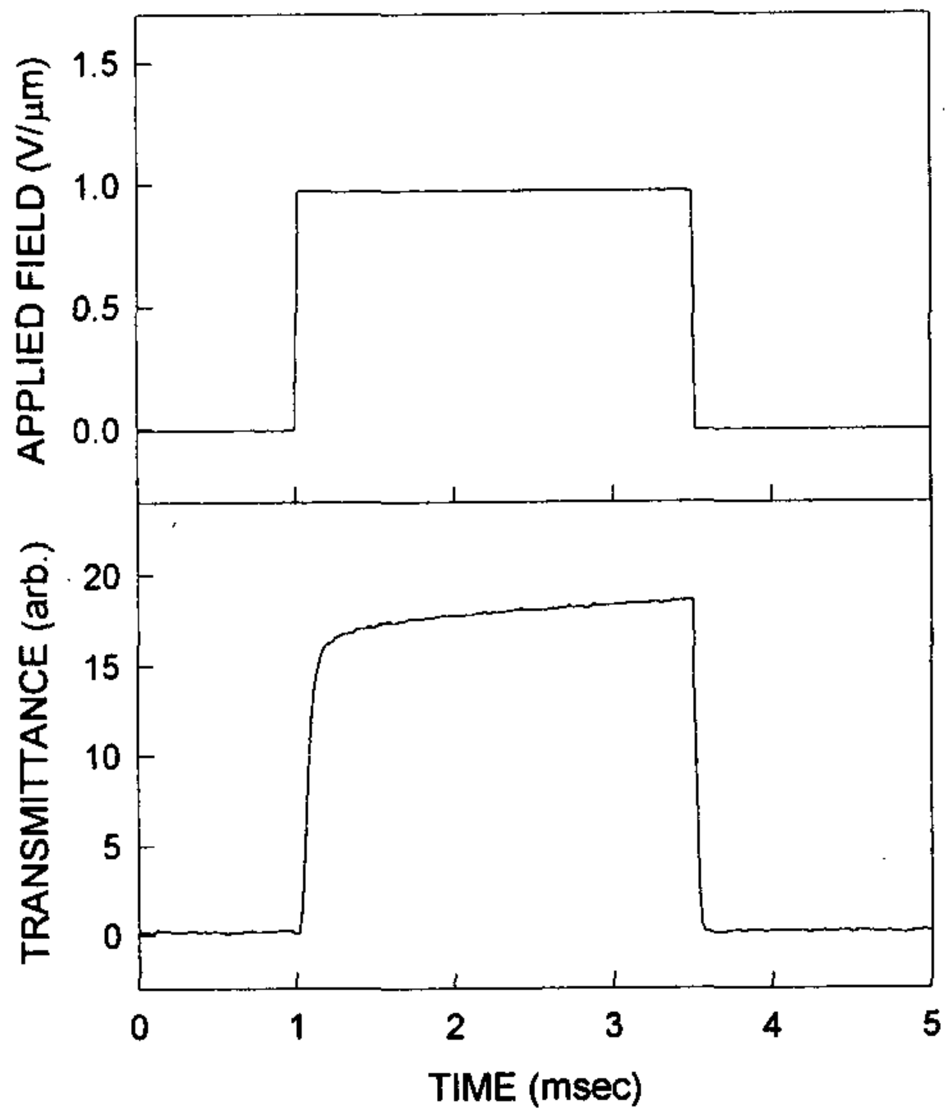


Fig. 4. The dynamic EO response of VC-DHFLC cell to the electric field of a unipolar square waveform.

[1] M. Schadt *et al.*, Nature **381**, 212 (1996).
[2] M. Oh-e *et al.*, Proc. Int'l Display Res. Conf. '95, 577 (1995).
[3] N. A. Clark *et al.*, Appl. Phys. Lett. **36**, 899 (1980); Ferroelectrics **85**, 79 (1988).
[4] L. A. Beresnev *et al.*, JETP Lett. **46**, 413 (1987).