Rubbing-free, vertically aligned nematic liquid crystal display controlled by in-plane field

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We fabricated a homeotropically aligned nematic liquid crystal display with positive dielectric anisotropy, whose on and off states are controlled by in-plane field. The rubbing-free device, dark in voltage-off state, reveals bright uniformity in all directions due to the dual domainlike director configuration in the voltage-on state. The electro-optic characteristics of one prototype with excellent viewing angles are reported herein. © *1997 American Institute of Physics.* [S0003-6951(97)03645-0]

Twisted nematic (TN) liquid crystal displays (LCDs) have been mainly used for notebook computers in spite of their narrow viewing angle characteristics. However, improving the viewing angle is a prerequisite for the replacement of cathode ray tube (CRT) displays by LCDs in monitor and TV markets. Recently, new concepts of LCDs employing the in-plane switching (IPS) mode,[1–3] and vertical alignment (VA) with compensation film[4,5] and homogeneous to twisted planar (HTP) transition[6] have been suggested. Although the IPS mode shows wide viewing angle characteristics comparable to the CRT displays, the cell gap margin is narrower and the response time is rather slower than that of the TN mode. Furthermore the IPS mode exhibits slight color shift in oblique viewing angles. The VA mode with negative birefringent film shows a viewing angle range greater than 70° in polar angle for all azimuthal directions and a very fast response time of less than 25 ms. However, in order to obtain the wide viewing angle, fabrication of dual domains is further necessary. This necessary step involves an additional process like mask rubbing or photoalignment, rendering the VA mode less practical. Moreover, most of the LCDs currently in use need a rubbing process which causes contamination by dust and electrostatic charges that may damage thin film transistors. Therefore the fabrication of the LCDs with rubbing-free process and wide viewing angle is most desirable if possible.

In this letter, we suggest rubbing-free LCDs associated with the deformed transition from vertical alignment induced by in-plane field switching[7,8] (VA+IPS). This device, with the addition of negative-birefringent compensation film, shows a very wide viewing angle comparable to the existing dual-domain VA mode.

Figure 1 shows the structure of a vertically aligned cell with an interdigital electrode and operation principles of the VA+IPS cell. For the voltage below Freedericksz transition threshold, V_{th}, the LC molecules are anchored homeotropically on both alignment layers so that the polarization state of incident light through the polarizer remains unchanged. Consequently, the light is blocked by the analyzer, giving rise to a completely dark state. However, light leakage at off-normal directions occurs, resulting in a low contrast ratio. This light leakage can be reduced with the addition of negative-birefringent film as described in the previous paper.[5] In the on-state, i.e., $V > V_{th}$, the LC molecules try to align parallel to the in-plane field and thus the LC molecules near the electrodes tilt down towards the center, whereas those at the center line remain unchanged. With this transition, when the tilted LC director makes an angle of 45° from the polarizer transmission axes, the polarization state of incident light through the polarizer becomes elliptic due to the phase retardation and thus the light is transmitted through the analyzer.

We have constructed several cells to investigate the characteristics of this device, varying the cell gap, electrode distance, and liquid crystals. Here we report the electro-optic characteristics of one such cell.

The indium tin oxide (ITO) was deposited on the bottom glass substrate, and the interdigital electrodes with an electrode distance of 20 μm and an electrode width of 10 μm were patterned through a photolithographic process. The top glass substrate has no electrode on it. The vertical alignment layer from Japan Synthetic Rubber Co. (JALS-204) was coated on both substrates. The two glass substrates were then assembled to give a cell gap (d) of 4.2 μm. The liquid crystal with positive dielectric anisotropy from Chisso Co. (Δn

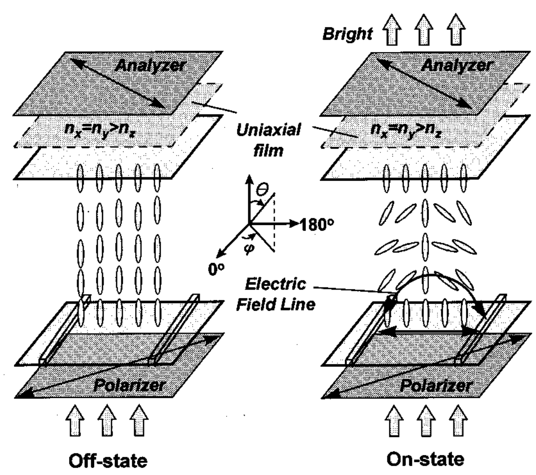

FIG. 1. The schematic diagram of the VA+IPS cell with molecular director configuration in off- and on-states. The negative birefringent film is inserted between analyzer and top substrate.

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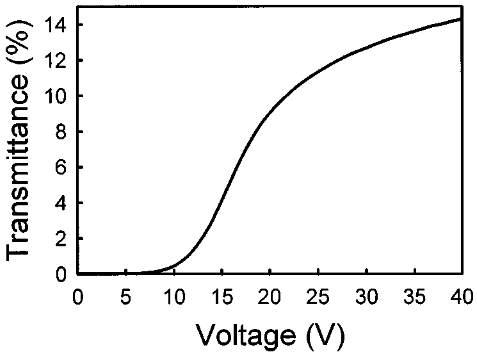

FIG. 2. Voltage-dependent optical transmission curve.

$=0.067$ at $\lambda=589$ nm, $\Delta\varepsilon=8.4$) was filled at room temperature.

For electro-optic measurement, the halogen lamp was used as a light source and a square wave, 60 Hz voltage source from a function generator was applied to the sample cell. The light passed through the cell and was detected by a photomultiplier tube.

Figure 2 shows the transmitted light intensity as a function of applied voltage. The light transmission starts occurring at an applied voltage of 7 V, and the transmission becomes almost saturated at 40 V. The transmission characteristics at normal direction are a function of $\sin^2(\delta/2)$, where $\delta=2\pi d\Delta n/\lambda$ is the phase retardation. Therefore, for a cell with $d\Delta n>\lambda/2$, the transmission will go down with further increasing voltage. The maximum transmission voltage, which depends on the distance between electrodes, the cell gap, and the LC material, can be reduced to about 5 V by increasing the cell gap and reducing the electrode distance.[3]

Figure 3 shows the viewing angle dependence of brightness. The reference is the light intensity with bias voltage of 40 V at normal direction. As can be seen clearly from the figure, the uniformity in brightness is greatly improved compared with that of the conventional cell associated with a single domain in deformation of vertical aligned phase (DAP).[4,9] Normalized transmission exceeds 30% within a polar angle of 60° in all directions. This results from the configuration of a dual-domainlike LC director by in-plane switching.

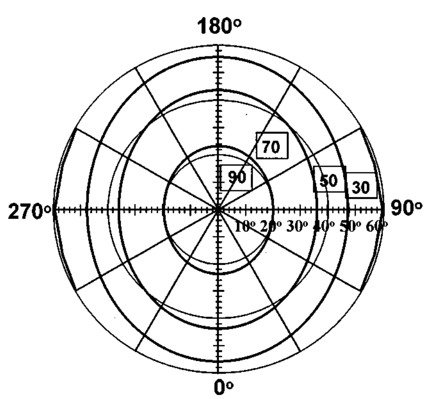

FIG. 3. The viewing angle dependence of light transmission. The reference is the light intensity with an applied voltage of 40 V at normal direction.

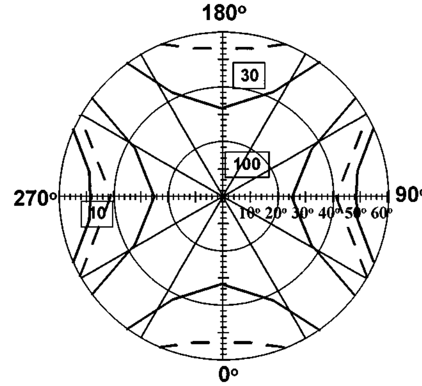

FIG. 4. The iso-contrast curves of the VA+IPS cell with compensation films.

We next investigate the dynamic behavior and microscopic observation of this device. The rising time with an applied voltage of 40 V is 11 ms and the decay time is 9 ms. This speed is about the same as that of cell in the VA mode. We observe the transmission pattern by a polarizing microscope. Before the voltage is applied below the threshold, the cell shows complete dark except the region near the sphere spacers. As the voltage increases above the threshold, the transmittance starts occurring at the region near the electrodes and the transmission region extends to the whole space. Disclination lines exist at the center between the electrodes because the LC layers do not move through the whole cell gap at the center, i.e., the directors are pushed towards the center from both sides. These lines are very stable, and are not disturbed even in an applied voltage of 50 V. They do not move around the other areas and therefore do not affect the quality of the display.

We measured the contrast ratio of this device using negative-birefringent compensation film as shown in Fig. 4. The film $[(n_x-n_z)\ d=160$ nm at $\lambda=589$ nm$]$ obtained from Nitto Denko Co. was used. The device clearly shows fourfold and mirror plane symmetries in an iso-contrast curve and the region with contrast ratio greater than 10 is superior to that of the conventional TN cell and comparable to that of the dual-domain of the VA cell with compensation film.[4] The viewing angle characteristics in 45° diagonal directions are especially superb.

In summary, the vertically aligned nematic LCD with positive dielectric anisotropy of the LC whose on- and off-states are controlled by the in-plane field, shows a much wider viewing angle than that of the conventional TN cell. This device does not require the rubbing process of alignment layers, thus saving cost and prossing steps in mass production of active-matrix LCDs. We expect that this concept of device is a step forward for application to wide viewing angle active-matrix LCDs.

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