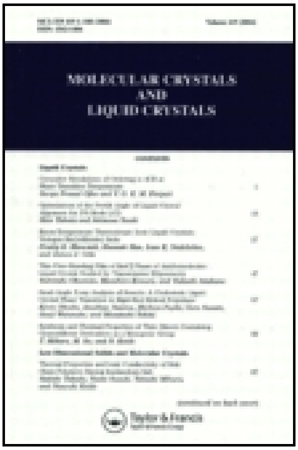

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Viewing Angle Controllable Liquid Crystal Display by Thermally Variable Retardation Layer

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We propose a new structure of a viewing angle controllable liquid crystal display (LCD) consisting of a conventional liquid crystal display (LCD) panel and a thermally variable retardation layer (TVRL) established by uniformly aligned LC cell with transparent indium-tin-oxide electrodes for Joule heating. In the TVRL, nematic phase is transitioned into the isotropic one by Joule heating. From numerical simulations, the intrinsic wide viewing angle was achieved at the isotropic phase of the TVRL by Joule heating, while the narrow viewing angle was obtained at the nematic phase of the TVRL. The structure of the viewing angle control proposed here is adoptable to all LCD modes with the wide viewing angle characteristics.

Keywords: retardation layer; thermal property of LC; viewing angle control LCD

PACS Numbers: Codes

I. INTRODUCTION

Various techniques such as patterned vertical alignment (PVA), multi-domain VA (MVA) mode, in-plane switching (IPS) mode, fringe

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field switching (FFS) mode, and optically compensated bend (OCB) mode, have been widely developed to improve viewing characteristics of nematic liquid crystal displays (LCDs) [1–8]. Also, as mobile electronic devices at hand become more affordable, the security of privacy has recently become one of crucial issues in display functionality. Sometimes displayed information would be shared to other peoples and sometimes should be secured from the others in public places. To correspond to such needs in mobile environment, a controllable display to viewing angles is urgently required to change between public and private modes: a wide viewing angle (WVA) characteristic for public mode and a narrow viewing angle (NVA) characteristic for private mode. To control the viewing angle characteristics, various methods have been proposed by adopting multiple LC layers or a dual backlight system [9–13]. In such approaches, however, the complex optic system as well as high cost components is inevitably employed to establish dual WVA and NVA modes.

In this paper, we propose a new method controlling a viewing angle of LCD through a thermally variable retardation layer (TVRL) and report on the numerical simulations of the LCD with the TVRL established by homeotropic or homogeneous aligned LC cell with transparent indium-tin-oxide (ITO) electrodes for Joule heating. When the TVRL is in isotropic phase by Joule heating, the optical property of the whole LCD is governed just by that of the main LCD panel and then WVA characteristics is achieved. On the other hand, when TVRL is in aligned nematic phase by cooling or no heating, the optical property of the LCD at off axis is influenced crucially by TVRL even though that at front side is not influenced, and then NVA is achieved. In our structure, the TVRL is attachable to other LCDs and thus wide viewing LCD modes such as PVA, MVA, IPS, FFS, and OCB modes can be used as a main display panel. Here, we used PVA mode as the main LCD panel for simulations of controlling the viewing angle characteristics.

II. SIMULATION

The structure of the viewing angle controllable LCD proposed here is shown in Figure 1. The birefringence of Δnd in the TVRL plays important role in the viewing angle characteristics of the whole LCD with the TVRL. As aforementioned, because the optical property of the viewing angle controllable LCD is governed just by that of the main LCD panel for isotropic phase through heating the TVRL (Fig. 1a), the widest viewing angle is obtained in the conventional PVA mode without the TVRL. At normally homeotropic state of the TVRL, the

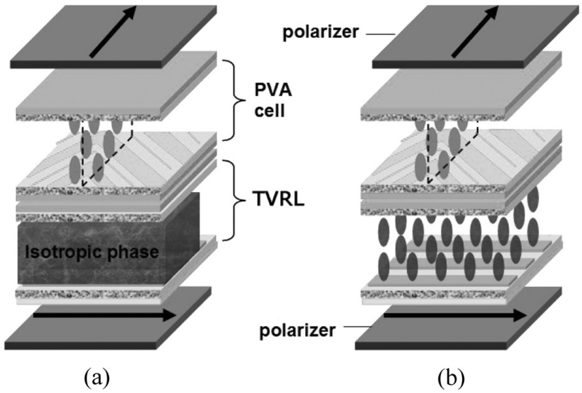

FIGURE 1 The cell structure of a viewing angle controllable LCD. (a) WVA mode at thermally activated state (isotropic phase) and (b) NVA mode at normally homeotropic state (isotropic phase) of the TVRL.

wide viewing angle characteristics would be degraded due to strong dependence of the birefringence on the polar angle (Fig. 1b).

In general, the LC materials for the TVRL possess as low nematic-isotropic transition temperature (T_{NI}) as in the vicinity of room temperature to reduce power consumption by Joule heating and heating effect on the main LCD panel. For simulation, we used material parameters of E7 (E. Merck), as the LC in TVRL, of which T_{NI} is about 58°C. To calculate the viewing angle of a PVA LC mode

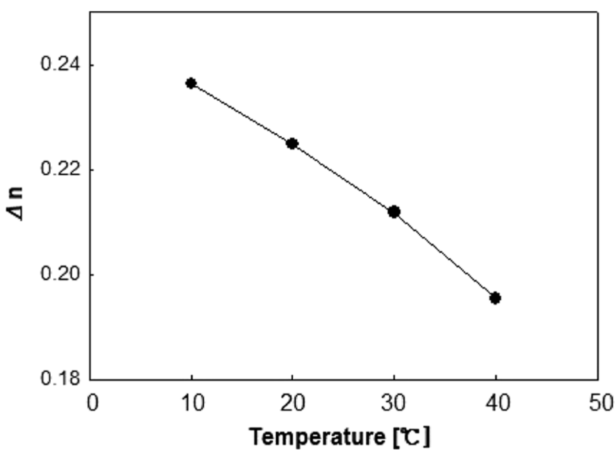

FIGURE 2 The refractive anisotropy of E7 as function of temperature.

with TVRL, a commercial simulator of TechWiz LCD (Sanayi System Co., Ltd., Korea) was used. For simulation, the refractive anisotropy of the VA LC material and the cell thickness were used to be 0.0824 and 4.36 μm in the conventional PVA mode, respectively. Here, an operating voltage of the PVA mode was used to be 7.5 V.

The refractive anisotropy of E7 for the TVRL is 0.2255 at room temperature and its temperature dependence is shown in Figure 2 [14]. It should be noted that the optical properties are governed by

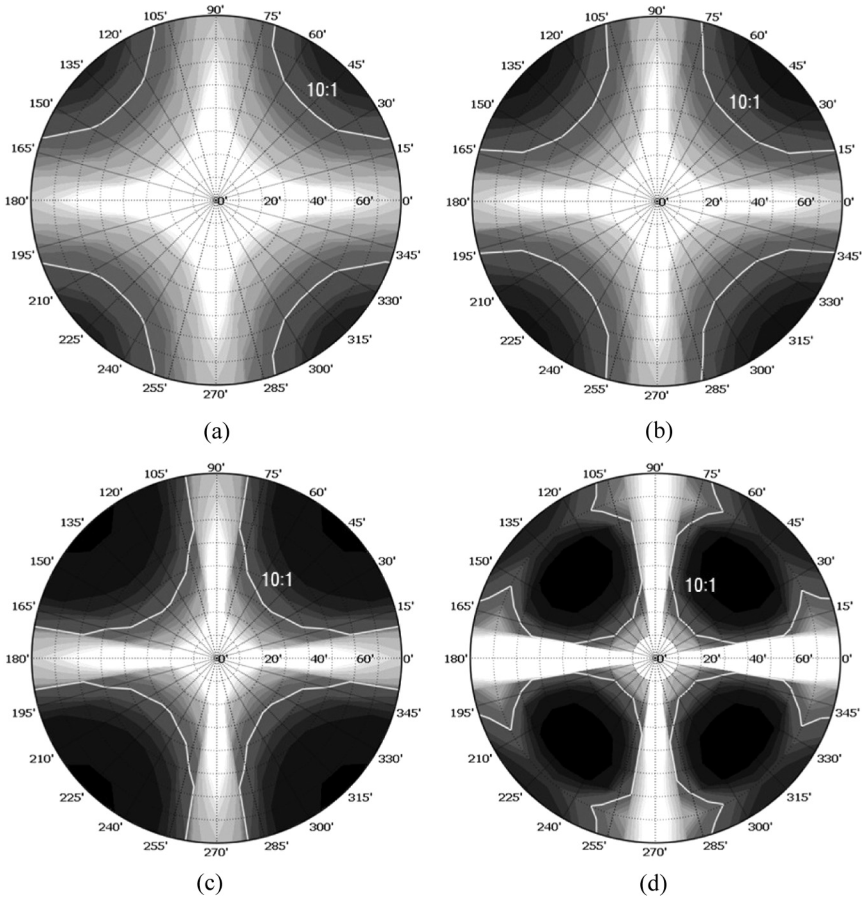

FIGURE 3 The contours of the contrast ratios of the PVA LC mode with the TVRL for various retardations (Δnd) of the TVRL. (a) $\Delta nd = 0.0$, (b) 1.0, (c) 1.7, and (d) 2.2. The solid lines in each contour represent the boundaries of the contrast ratio 10:1.

the birefringence of the TVRL. As shown in Figure 2, the refractive anisotropy of the E7 for the TVRL gradually decreases and reaches to zero above the T_{NI} with increasing temperature and thus the viewing angle characteristics of the PVA LC mode with the TVRL are continuously controlled within a certain range. For simplification of the simulation, we fixed the cell thickness (d) of the heating layer, TVRL, and changed the refractive anisotropy (Δn) from 0 to 0.2255. It should be noted that the refractive anisotropy even in the homeotropically aligned structure still depends on temperature.

III. RESULTS AND DISCUSSION

The viewing angle characteristics of the PVA LC modes with the TVRL simulated here are shown in Figure 3. In the isotropic phase of the TVRL produced by Joule heating, the intrinsic viewing characteristics of the PVA LC mode were obtained as shown in Figure 3(a). In such case, the effect of the TVRL is negligible due to the independences of incident direction and polarization in the isotropic phase of the TVRL. Here, excellent contrast ratio was achieved within a range of our simulations [WVA mode].

In principle, the contrast ratios are gradually reduced with increasing the birefringence of the TVRL within a range of our simulation because of the enhancement of the birefringence-dependence on the polar angle as shown in Figure 3. In the NVA mode with the

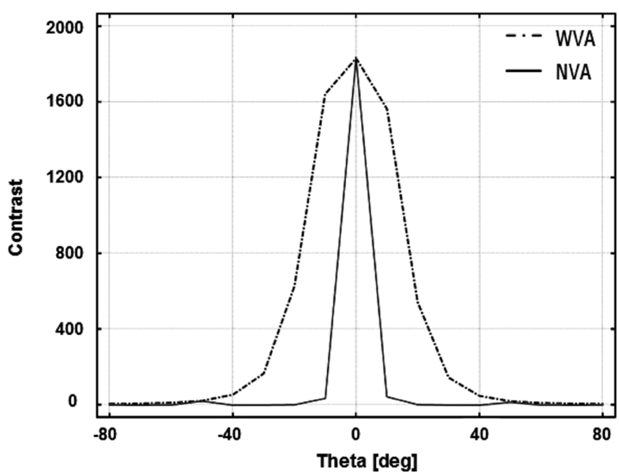

FIGURE 4 The contrast ratios of the WVA ($\Delta nd = 0.0$) and NVA ($\Delta nd = 2.2$) modes along the diagonal axis.

birefringence of $\Delta nd = 2.2$, the polar angle with the contrast ratio 10:1 was decreased up to 20° along the diagonal axis as shown in Figure 3(d). Here, the LC molecules in the TVRL shows a nematic phase and is uniformly aligned by the alignment layer. In the homeotropically aligned structure, note that the refractive anisotropy at a normal incidence does not effect on the contrast ratio but that at any oblique incidences produce the degradation of the contrast ratio. Therefore, the viewing angle characteristics could be controlled by the heating layer of the homeotropically aligned LC structure.

Figure 4 shows the contrast ratios of the WVA mode, where the LC in the TVRL transitions isotropic phase by Joule heating, and the NVA mode at the nematic phase with $\Delta nd = 2.2$ along the diagonal axis. It is obvious that the viewing angle is remarkably reduced by the TVRL with a nematic phase.

IV. CONCLUSION

We proposed a new structure of a viewing angle controllable LCD with the TVRL fabricated by homeotropic aligned LC cell with transparent indium-tin-oxide (ITO) electrodes for Joule heating. From the numerical simulations of the PVA LC cell with the TVRL, the WVA mode was obtained by Joule heating in the TVRL where the LC molecules transitioned into isotropic phase and thus no influence occurred on the viewing angle characteristics. On the other hand, the NVA mode was achieved at the nematic phase in the TVRL. The proposed method controlling viewing angle of the LCD would be expected to play an important role in the mobile electronic devices with securing privacy.

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