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Maximization of an Electric Field Penetrating an Optically Isotropic Phase Liquid Crystal for Low Operating Voltage Display

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Liquid crystal displays (LCDs) correlated with polymer-stabilized optically isotropic state LC mixtures show relatively low light efficiency and very high operating voltage when the device is structured by interdigitated electrodes which generate in-plane electric fields. This is because the horizontal field intensity is not strong enough and half of the field is wasted by penetrating the substrate and the Kerr constant of the mixture is not high enough. We propose an electrode structure which can absolutely diminish the operating voltage while keeping the transmittance by generating in-plane electric fields penetrating the LC layer twice stronger than that of the conventional one.

Keywords Blue phase; Kerr effect; optically isotropic liquid crystal

1. Introduction

Polymer-stabilized blue phase liquid crystals (PSBP LCs) and optically isotropic nano-structured LC mixtures have drawn much interest regarding as new generation technique in liquid crystal displays (LCDs) [1,2] due to its isotropic-anisotropic transition by Kerr effect. Although nematic LC devices with wide viewing angle such as in-plane switching (IPS) [3], fringe-field switching (FFS) [4–7], patterned vertical alignment (PVA) [8,9] and multi-domain vertical alignment (MVA) [10,11] modes are mainly applied to LC-televisions, but especially for a large display it is always difficult to align LC in one particular direction for achieving these modes.

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So in recent times lots of research are going on PSBP LC mode due to its several excellent advantages over nematic LCs such as: (1) optically isotropic state without electric field, allowing simple device fabrication process without mechanical alignment treatment, (2) microsecond order response time opposing high elastic force, established by the polymer networks [12–14]. Elimination of surface treatment simplifies the device fabrication procedure and reduce the fabrication time as well, in this case. Owing to very fast response time, LCDs with field sequential technique [15,16] can be realized and in this case, without the color filter, the resolution can be increased three times and light efficiency can be enhanced more than 10% of incident light. Besides, the characteristics of the fast response time should be the most impressive feature for high frequency driving scheme and 3-dimensional display approach.

Nevertheless, this PSBP LC device has two big challenges to be overcome: (1) high operating voltage due to the high elastic force and low Kerr constant of the PSBP LCs material, (2) relatively low transmittance when interdigitated electrodes are used to generate in-plane electric field. Even though there are positive stream of a few approaches to lower the operating voltage [17–20], the design of electrode structure is not so easy for the device fabrication. Therefore, relatively easier and reasonable device fabrication process must also be achieved.

2. Switching Principle and Simulation Conditions

The device is configured with the cell structure as shown in Figure 1. The PSBP LCs layer is sandwiched between crossed polarizer. Figure 1(a) and (b) show conventional inter-digitated electrode structure and proposed electrode structure for reducing the operating voltage, respectively. In the case of conventional interdigitated electrode configuration as shown in Figure 1(a), electric field is formed between the electrodes to induce birefringence in PSBP LCs. Since electric lines of force are drawn perpendicular to the surface of electrodes considering vector nature of lines, field lines are symmetrically shaped as an ellipse by a standard extension of electrodes parallel to the substrates. However, the half of the electric field is ineffective because

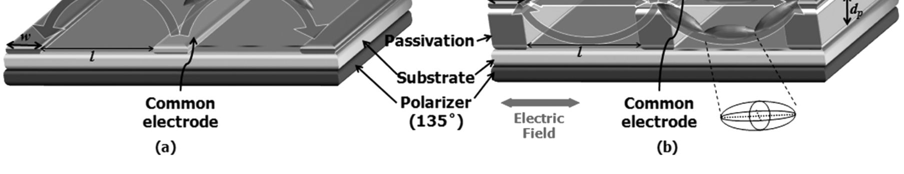

Figure 1. Device configuration of voltage on state using PSBP LC. (a) Normal inter-digitated electrode, and (b) proposed double penetrating in-plane electric field mode.

the field penetrates through the substrate, not the LC layer. To lower the operating voltage of the LC device, utilization of the electric field should run with an effective way for the intensity of the electric field. According to the physical phenomenon of quadratic electro-optic Kerr effect, an electric field E can be expressed as Eq.(1) [21]:

$$\Delta n_i = \lambda K E^2 \tag{1}$$

where Δn_i is induced birefringence, λ is wavelength of an incident light, K is Kerr constant and E is intensity of an electric field. For low operating voltage, the Kerr constant of PSBP LC mixture should be high enough without trade-off to affecting the other properties of it such as viscosity, ion-purity, and hysteresis, which is not so simple to overcome. Therefore, E should be maximized, which can be realized by proposed electrode structure. In the case of proposed electrode structure as illustrated in Figure 1(b), electric field is formed by electric field lines penetrating both up and down sides between the electrodes which can be called double penetrating in-plane electric field mode. To realize such a structure, both electrode andpassivation layer should be patterned by a proper and reasonable way which has been developed by a few research group [22,23].

In order to explain the performance of the proposed device structure, electro-optic properties were simulated by calculating a few steps. The distribution of electric field was calculated by Laplacian equation, and birefringence was determined from changes of refractive indices considering Kerr effect by detecting electric field intensity in each region of the cell. Then 2×2 extended Jones matrix method [24] was utilized for transmittance of the device, thereby outputting other electro-optic properties. Basically, we set the condition as Δn_i cannot be over the refractive indices of a host LC (Δn_h). Here, the condition of the simulation was set as $\Delta n_h = 0.26$, the layer thickness of the PSBP LCs $(d) = 6\,\mu\text{m}$, the electrode width $(w) = 3\,\mu\text{m}$, and the length between electrodes $(l) = 6\,\mu\text{m}$. Two different patterned passivation layer thickness (h) 2 and $3\,\mu\text{m}$, and two different Ks $6.2 \times 10^{-9}\,\text{m/V}^2$ and $62 \times 10^{-8}\,\text{m/V}^2$ (100 K) have been considered.

The transmittance (T) of the device can be calculated from the following equation:

$$T/T_0 = \sin^2 2\Psi \sin^2\left(\frac{\pi di\Delta n_i(V)}{\lambda}\right) \tag{2}$$

which is based on the mechanism of light modulation depending on retardation of the phase in the LC medium. Here Ψ is the angle between the induced optic axis and the transmission axis of the one of the crossed polarizers. For maximum transmittance, Ψ and $d\Delta n$ should be 45° and $\lambda/2$, respectively.

3. Results and Discussion

Basically, all of operation was performed by applying two transistors driving scheme which is essentially reducing the operating voltage as half of it [17]. Figure 2 shows the voltage-dependent transmittance for different device configurations. As shown in the figure, the operating voltage of normal inter-digitated electrode is found to be at 80 Vrms.

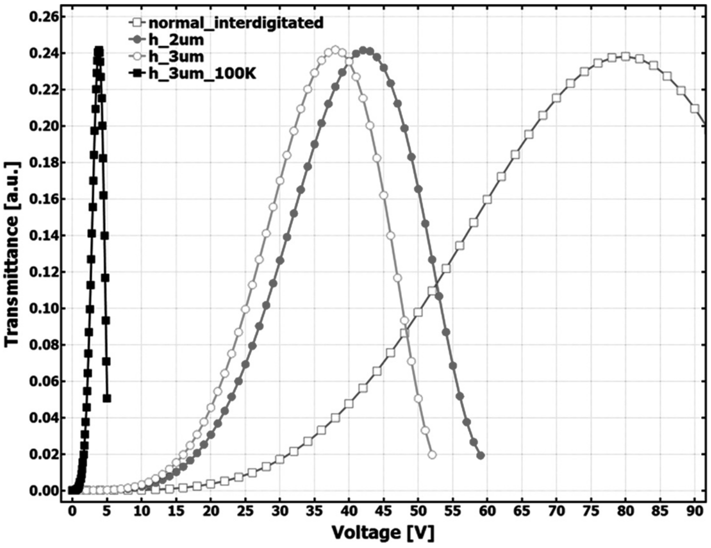

Figure 2. Simulated voltage dependent transmittance curves of normal inter-digitated electrode, proposed double penetrating in-plane field mode with patterned passivation thickness of 2, 3, and 3 μm with 100 *K*.

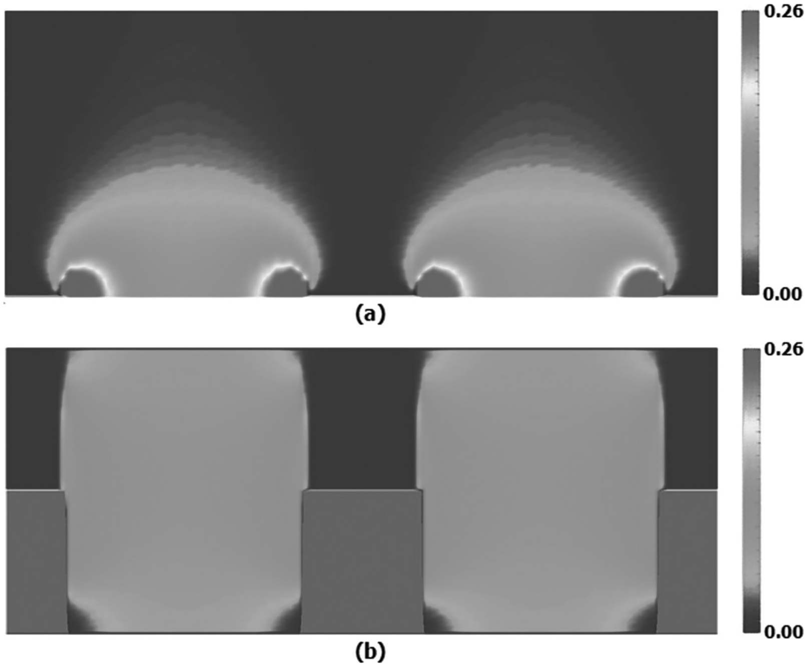

Figure 3. Induced birefringence (Δn_i) distribution for (a) Normal inter-digitated electrode, and (b) Proposed double penetrating in-plane electric field mode.

On the other hand for proposed double penetrating in-plane field mode the operating voltages are close to 42 and 38 V rms for $h = 2$ and 3 μm respectively, taking $K = 6.2\,\mathrm{nm/V^2}$. Thus the operating voltage in the proposed mode have been minimized up to over half of that in the case of normal interdigitated electrode for $h = 3$ μm. More reasonable result can be inferred that the strong and deeper electric fields are generated between the pixel and common electrodes. The former plays a key role reducing operation voltage while the transmittance remained the same as normal case. Moreover, it went down to 3.8, where the K was a hundred fold higher. Besides, the low operating voltage would reduce the power consumption of the display device.

Figure 3 shows the induced birefringence Δn_i distribution caused by the horizontal electric field Ey in the conventional interdigitated electrode structure and in proposed double penetrating in-plane field mode. Referring to Figure 3(a), the induced birefringence Δn_i fully saturated to Δn_{max} only near the patterned electrodes edges and abruptly decreased on the patterned electrodes for conventional interdigitated electrode structure. At the center area between the patterned electrodes, conventional interdigitated electrode structure exhibited smaller Δn_i than that of near the edges. Although Δn_i was small, since it had broad distribution, it is clear that $d_i \Delta n_i$ seems to reach the $\lambda/2$ phase at higher voltage. On the contrary, in Figure 3(b), proposed double penetrating in-plane field mode showed the effective induced birefringence Δn_i distribution. The electric fields penetrate both up and down sides between the electrodes. This is the reason why the proposed double penetrating in-plane field mode is needed to lower the operation voltage for BP LCD.

3. Conclusions

In this paper, we have proposed double penetrating in-plane electric field mode for effectively reducing the operating voltage while maintaining the transmittance by generating in-plane electric fields via up and down region of the electrodes by patterning a passivation layer. Consequently, blue phase LCDs which adopt the proposed electrode shape can be improved with lower operating voltage up to over half of in the case of normal inter-digitated electrode. The latter enables high frequency driving scheme and 3-dimensional display which can have characteristic of the fast response time.

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