A New Liquid Crystal Fringe-Field Switching Device with Superior Outdoor Readability

Seung Min Seen, Mi Sook Kim[1], and Seung Hee Lee*

Polymer BIN Fusion Research Center, Department of Polymer-Nano Science and Engineering, Chonbuk National University,
Jeonju, Jeonbuk 561-756, Korea
[1]*Micro System Gr., Devices & Materials R&D Lab., LG Electronics Inc., 16 Woomyeon-dong, Seocho-gu, Seoul 137-724, Korea*

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A new liquid crystal (LC) device driven by fringe-field switching (FFS) with superior outdoor readability is proposed. In this structure, the bottom substrate has patterned floating metals which are positioned below the center of the pixel electrode and the center between pixel electrodes and above metals, in-cell retarder with quarter wave phase retardation (QWPR) exists and under them, compensation film with QWPR does. And light efficiency at these positions becomes maximal under any lighting conditions. As a result, it is possible for the new device to show both a single cell gap and superior outdoor readability even though it's not a transflective LC display.

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1. Introduction

Nowadays portable devices such as mobile smart phones, digital still cameras, personal multiple players are widely developed as a result of their increasing demand in the market.[1] For these mobile displays, the excellent electro-optic characteristics under outdoor state as well as indoor state are needed. Transflective liquid crystal displays (TR-LCDs) have been mostly used to outdoor applications because of their superior characteristics with outdoor legibility and low power consumption.[2–4] However, it is limited to LC modes with narrow viewing angle such as a single cell gap transflective display associated with vertical field-driven vertical alignment and a homogeneous cell with a compensation film driven by a vertical electric field.[5,6] Actually, the LC devices with a wide viewing angle driven by in-plane switching field or fringe electric field originally have a design issue with regard to its ability which decides the ratio of transmissive to reflective areas for applying to TR-LCDs.[7,8] It is highly related to the image quality characteristics of the LCD. And also, these modes remain technical challenges like a single-cell gap which gap which does not require additional processes and low operation dynamic range.

In this paper, we propose a new LC device driven by fringe-field switching (FFS) with a good outdoor readability. In this structure, the bottom substrate has patterned floating metals which are positioned below the center of the pixel electrode and the center between pixel electrodes and above metals, in-cell retarder with QWPR exists and under them, compensation film with QWPR does. With this approach, the light efficiency at all these positions becomes maximal under any light condition even though it is not TR-LCDs. As a result, the device shows an excellent outdoor readability though it is a single cell gap display. Moreover it has superior electro-optic characteristic than a conventional transmissive FFS mode due to its good light efficiency at all positions under indoor state. The structure and performances of this new proposed device were optimized using a commercial three-dimensional LC simulator, "Techwiz LCD" (developed by Sanayi System, Korea), where the motion of the LC director is calculated based on the Eriksen-Leslie theory and 2×2 Jones matrix[9,10] is applied to calculate optical transmittance.

2. Simulational Results and Discussion for New FFS LC Mode

Figure 1 shows cross-section and top views of a new device. As appeared, the electrodes only exist on the bottom substrate. The common electrode exists in the plane form and the pixel electrode with patterned slits exists with a width (w) and a distance (l'). The w and l' are designed to be 3 and 5 μm, respectively, which are commercially used.[11,12] With this structure, the fringe electric field having both horizontal and vertical component is generated with a bias voltage. The slit angle (SA), θ is 0° in this case. The rubbing direction is given to horizontal direction to make an angle of -7° with respect to the horizontal component of the fringe field. The cell gap (d) is 3.8 μm. Here, the LC material employed has its physical properties as follows; extraordinary and ordinary refractive indices $n_e = 1.5861$, $n_o = 1.4861$ (at $\lambda = 589$ nm), dielectric anisotropy $\Delta\varepsilon = 8.2$, rotational viscosity $\gamma_1 = 86$ mPa·s and elastic constants $K_{11} = 13.3$, $K_{22} = 7$, $K_{33} = 12.6$ pN. As depicted in Fig. 1(b), the bottom substrate has patterned floating metals which are positioned below the center of the pixel electrode and the center between pixel electrodes. Above metals, in-cell retarder exists and under them, compensation film with QWPR does. Here, place without the floating metal and the other with it are defined as (S_1) part and (S_2) part, respectively. With this cell structure, LC molecules are homogeneously aligned with their optic axis parallel to the transmission axis of the bottom linear polarizer. The bottom polarizer is crossed to the top one. As a result, it shows normally black in initial state and transmittance becomes maximal while the LC directors are rotated close to 45° by fringe electric field. In this case, in-cell retarder and floating metal never affect on the operation voltage (V_{op}) because they exist below common electrode.

Figure 2 shows the detailed optical configuration of the new device between crossed polarizers. At the (S_1) part, we can see that the optic axis of linearly polarized light from bottom polarizer keeps its initial polarization direction while it passes through compensation film with QWPR and in-cell retarder. It is also blocked by top polarizer because the optic axis and top one cross with each other. In case that V_{op} is applied, LC directors are substantially twisted to be about 45° away from their initial positions. This LC layer is equivalent to a half-wave plate which further rotates the input linearly polarized light to 90°. As a result, it becomes white state.

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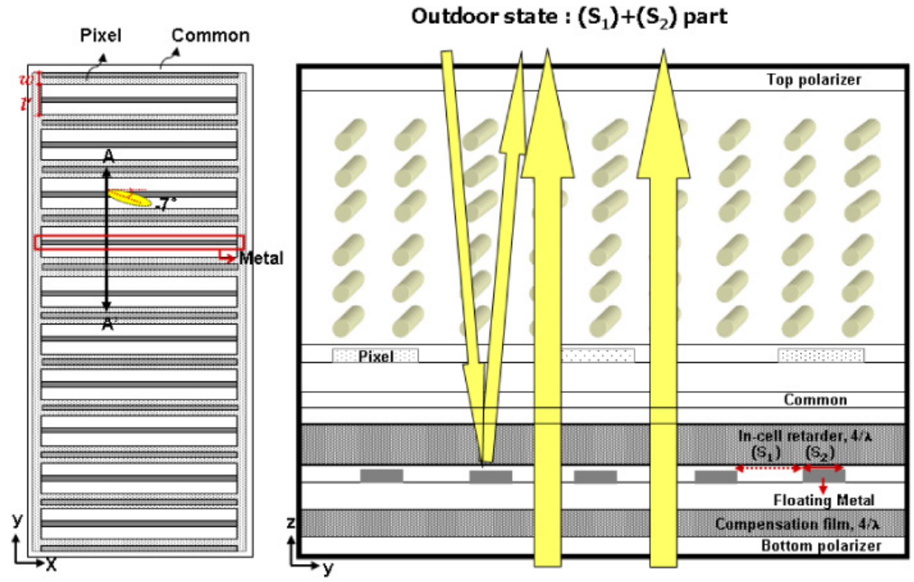
*E-mail address: lsh1@jbnu.ac.kr



(a) (b)

Fig. 1. (Color online) Schematic pixel structure of the new proposed LC device: (a) top view; (b) cross-sectional view.

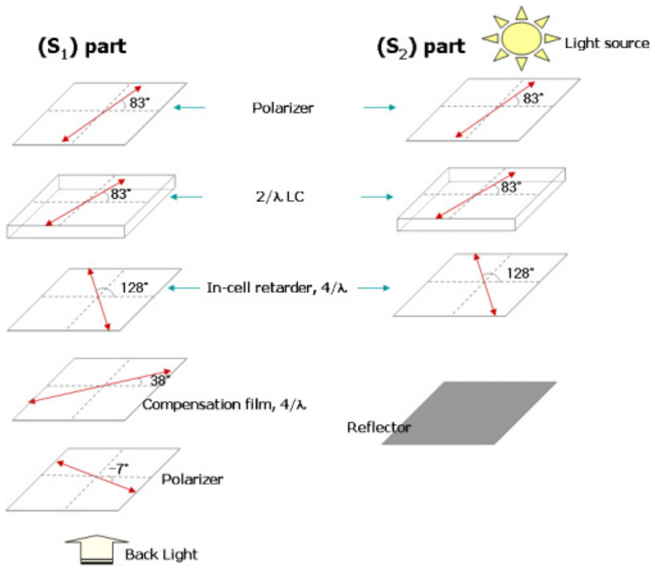
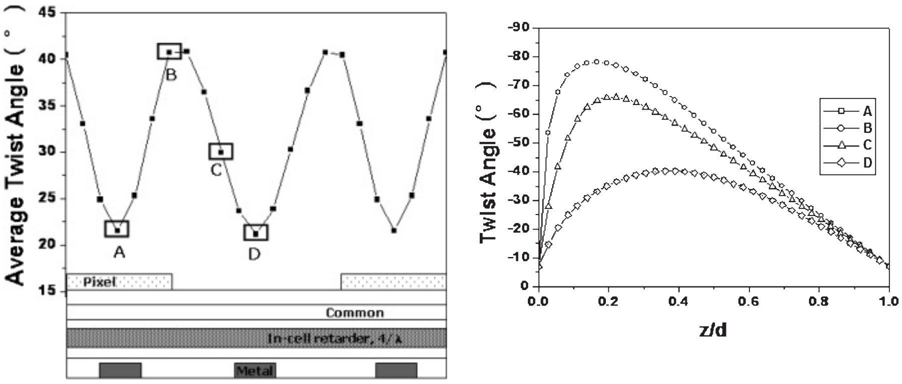


Fig. 2. (Color online) Optical configuration of the proposed LC device.

At the (S_2) part, top polarizer's axis and the LC axis coincide with each other, and below the LC layer, the in-cell retarder with QWPR making 45° with respect to the polarizer exists, and finally the patterned metal layer in the bottom position exists. In the $V_{\rm off}$ state, the linearly polarized light from top polarizer keeps its polarization throughout the LC layer and it is first converted to a circularly polarized light by the in-cell retarder. And upon reflection from the patterned metal layer it crosses in-cell retarder and LC layer once again and becomes linearly polarized. Its optic axis is rotated to 90° from incident one and is blocked by the top linear polarizer. So, it exhibits black state. On the other hand, the LC directors in these areas are twisted ~22.5° away from their initial positions when $V_{\rm op}$ is applied because of the different profile of LC director according to the electrode position. That is why horizontal field, which makes LC director rotate, is minimized on the center of pixel electrode and center between pixel electrodes. So, the input light traversing LC layer passes along in-cell retarder with QWPR twice by the metal layer positioned in the bottom. The reflected one passes through the LC layer once more resulting that its optic axis becomes linearly polarized with a 90° rotation to the top polarizer. So we can see white state. Here, we can know this device perfectly meets both transmissive and reflective characteristics in the proposed simple single cell structure. So, it does not need to design transmissive and reflective area, respectively and then operate the LCs like TR-LCDs with excellent outdoor legibility.

Next, let us consider in detail the profile of the LC director according to the electrode position at $V_{\rm op}$ for this device, as depicted in Fig. 3. Here, A, B, C, D indicate the center position on the pixel electrode, pixel edge, 1.2 µm one away from pixel edge, 2.5 µm one away from pixel edge, respectively. Actually, LC mode driven by fringe electric field differs from the horizontal field strength according to the position of pixel electrode resulting that it exhibits different director profile upon position, as it is reported before.[13)] That is, LCs at position A, D, are twisted in average by ~22.5° due to horizontally generated weak fringe field while LCs at position B, C are twisted in average ~43 and ~30°, respectively. Figure 3(b) shows the twist angle of the LC along the vertical axis, which is z direction at the different position. From this, we can expect that the value of small twist angle at position A, D, is the main factor making transmittance decrease in a conventional transmissive FFS mode. But these areas having in average twist angle of ~22.5° are a condition generating good bright state in the reflective area. So we propose a new LC device driven by fringe electric field with floating metal layer which is positioned below these areas and above metals layer, in-cell retarder with QWPR exists and under them, compensation film with QWPR does. In this structure, it has superior light efficiency under any light condition since LC directors with a cell retardation value of $\lambda/2$ at the (S_1) part rotate



(a) (b)

Fig. 3. LC director profile at V_{op}: (a) average twist angle; (b) twist angle.

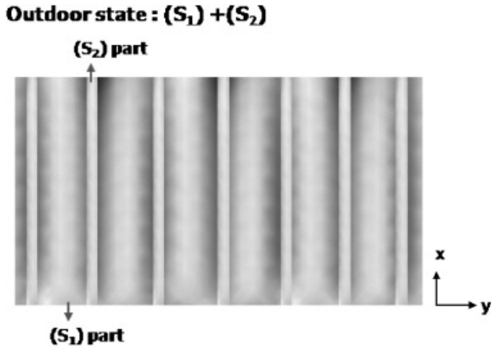


Fig. 4. Optic image of the new proposed device at V_{op}.

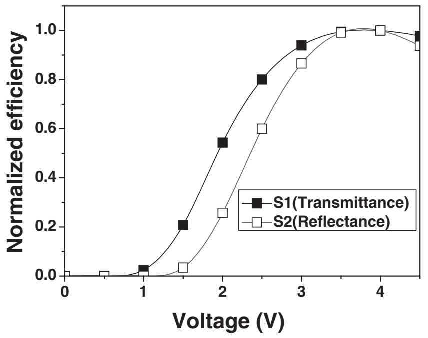


Fig. 5. Voltage-dependant normalized transmittance and reflectance for the new proposed device.

close to 45° from their initial positions and also them at the (S_2) part keep ~22.5° from there but the input light passes through them twice at the V_{op}.

Figure 4 shows the optic image of the new proposed device at the V_{op}. As depicted in Fig. 4, brightness at the (S_2) part of this device is maximal while the same position without patterned floating metal layer for a conventional transmissive FFS mode has lowest light efficiency due to less twist angle which is the same as ~22.5°. And also, the (S_1) part which originally has the strong electric field exhibits the good brightness. Therefore, this device has excellent electro-optic characteristic at any light condition. Figure 5 shows voltage dependant transmittance and voltage dependant reflectance curves at the (S_1) part and (S_2) part, respectively. The curves are well matched to be controlled by a single gamma curve because it has same V_{op} at all transmittance and reflectance regions. Therefore, it is very a required technique for the mobile devices because this new proposed device has low V_{op} (~4 V) with single gamma characteristic compared to FFS TR-LCD.

3. Conclusions

In conclusion, we proposed a new LC device driven by fringe electric field switching with a floating patterned metal layer. This structure makes excellent light efficiency not on the pixel edge but also on the center of the pixel electrode and the center between pixel electrodes. As a result, it exhibits both a single cell gap and superior outdoor readability. This device might be very useful in outdoor application, especially like personal mobile devices due to its high image quality, wide viewing angle, and simple cell design.

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