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The Static Electricity Resistant Liquid Crystal Display Driven by Fringe Electric Field

Mi Sook Kim[1,2], Seung Min Seen[3], and Seung Hee Lee[1*]

[1] *Department of BIN Fusion Technology and Department of Polymer-Nano Science and Engineering, Chonbuk National University, Jeonju 561-756, Korea*
[2] *New Device Team, Materials and Components Laboratory, LG Electronics Inc., Seoul 137-724, Korea*
[3] *2 Team, Mobile Communications Core Technology Development, LG Electronics Inc., Seoul 153-801, Korea*

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In this paper, we propose the static electricity resistant liquid crystal display (LCD) driven by fringe electric field. In the device, the conductive Cr metal playing role as black matrix (BM) in the top glass substrate is connected to the common electrode on the bottom substrate by the Ag transfer dotting. In addition, the common electrode also contacts to border chassis, allowing it to serve as the path for discharging the static charge generated on the top glass surface when peeling off the protective layer of the polarizer. Therefore, the electrostatic charges near BM or in the active region move fast enough to the CrBM for neutralization, while keeping the display in the neutral state electrically. The proposed LCD utilizes a liquid crystal mixture with negative dielectric anisotropy, allowing the device to be in much stable state against noise field generated by CrBM or external electrostatic discharge (ESD). We expect that this proposed structure is suitable to electrostatic resistant fringe-field switching (FFS)-LCD with a high image quality.

1. Introduction

Today, liquid crystal displays (LCDs) using a wide viewing technique have been greatly used in various applications such as mobile phones and notebook, and television products. Among several technologies, in-plane switching (IPS) mode[1,2] with wide viewing characteristics was the first one that showed high image quality, although it showed intrinsically low transmittance and high operating voltage. On the other hand, the fringe-field switching (FFS) mode,[3–10] which is driven by a fringe electric field, is the representative one that exhibits both high transmittance and wide viewing characteristics as well as low operating voltage.

In reality of FFS-LCD, both common and pixel electrodes are positioned on the bottom substrate. And fringe electric field is strongly generated near bottom substrate when a voltage is applied. It is vulnerable to the static electricity because there is no electrode on the top glass substrate. Moreover, it is most vulnerable to the static electricity when peeling off protective layer of polarizer after the panel is manufactured.[11,12] To resolve this problem, conductive indium–tin-oxide (ITO) layer is generally deposited on the backside of the top glass substrate and it contacts to the border chassis of the panel. This solution is the main cause of an increase in cost and an additional process. Moreover, it is not desirable from the point of recent market demand for the slim LCD. The reason is that the ITO coating process after the glass slimming is much difficult and the cost increases.

To overcome this problem, we propose the static electricity resistant device driven by fringe-electric field. The device structures and performances of the proposed LCD were optimized using a commercially available three-dimensional (3D) LC simulator TECHWIZ (Sanayi System) where the motion of the LC director is calculated, based on the Eriksen–Leslie theory and a 2×2 Jones matrix[13,14] is applied to the optical transmittance calculation.

2. Simulational Results and Discussion

Figure 1 shows top-view of conductive Cr BM and cross-sectional cell structure of the static electricity resistant FFS-LCD. As depicted in Fig. 1, the pixel electrode with plane shape is formed on the bottom glass substrate. The common electrode with a slit shape is formed above the pixel electrode. The passivation layer is positioned between them. The liquid crystal directors are aligned homogeneously with their optic axis parallel to the transmission axis of the top linear polarizer. The bottom polarizer is crossed to the top one. The width (w) of the common electrodes is 3 µm and the distance (l') between the electrodes is 5 µm. This is an optimal design condition for high transmittance and low operation voltage. The rubbing angle is 7°, with respect to the horizontal x component of the fringe field. The pretilt angle generated by the rubbing is 2°. The assembled top and bottom glass substrates provide a cell gap (d) of 3.8 µm. The liquid crystal with a negative dielectric anisotropy ($\Delta\varepsilon = -4.0$) and birefringence ($\Delta n = 0.0926$ at $\lambda = 589$ nm) from Merck is used for our simulations and experiments. The CrBM existed in the top substrate connects to the bottom common electrode by the Ag transfer dotting. As a result, CrBM plays a path to discharge the charged ions like in the ITO layer deposited on backside of top glass substrate for the conventional FFS. As well known, the FFS mode is a normally black mode, and the transmission becomes maximal when the LC director is rotated by near 45° by an applied voltage, given the birefringence of the LC medium.

From this structure, we can predict the discharging mechanism about the static electricity for the proposed device. Generally, the electrostatic charges on the top glass surface are generated when peeling off the protective layer from the polarizer for the conventional FFS-LCD. The charges have to be eliminated because they distort a field distribution which controls liquid crystal director for switching or the displayed images would be distorted. Since the CrBM in the top glass substrate is connected to a common electrode on the bottom glass substrate by the Ag transfer dotting in the proposed FFS-LCD and the common electrode are in contact to the border frame, the generated static charges positioned near BM or in the active region move fast to the CrBM and common electrode, as schematically explained in Fig. 1. Finally, the charges are all distributed to common electrodes through the path and the amount of remained charges are not large enough to affect

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

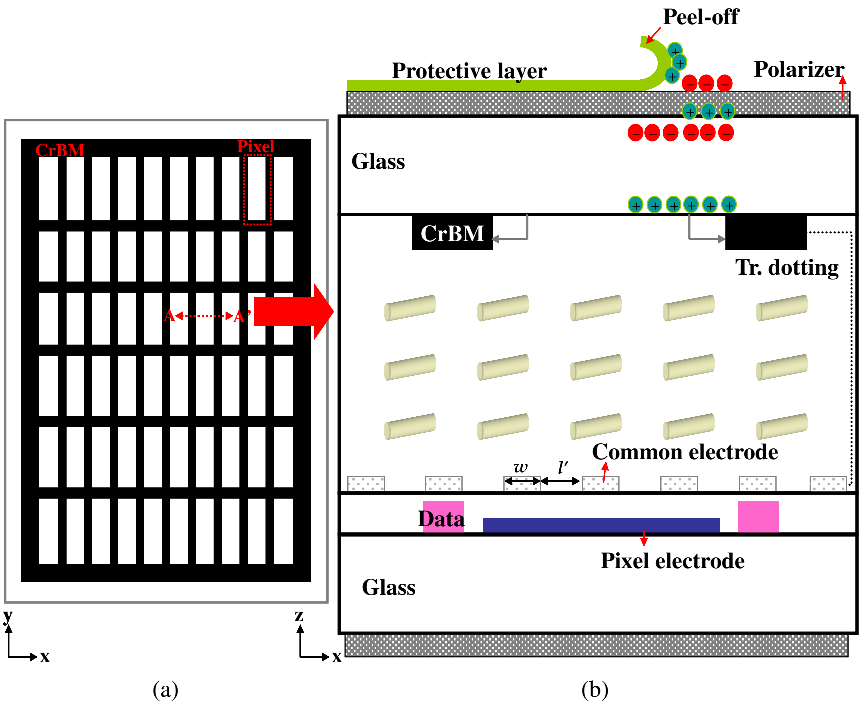

Fig. 1. (Color online) Cell structure of the static electricity resistant FFS-LCD: (a) top-view of CrBM and (b) cross-sectional view with CrBM on top substrate.

the field distribution. From this approach, the proposed FFS-LCD shows about the same level of strength against static electricity as the twisted nematic (TN)[15] or vertical alignment (VA)[16] LCD driven by the vertical field.

Next, to demonstrate this mechanism, we performed a 3D computer LC simulation. For simulation, we assume that 300 V assuming electrostatic discharge (ESD) test state is applied to the ITO layer on the back-side of top glass. As shown in Fig. 2(a), there was no light leakage, showing a stable dark state. In addition, it also shows uniform transmittance for white state at an applied operation voltage, as shown in Fig. 2(b). We assume that the structure with ITO layer on the backside of top glass substrate shows very stable characteristics about ESD. In the proposed device, the LC with negative dielectric anisotropy, which has an advantage in terms of the voltage-dependent dynamic stability, are used. Actually, the voltage-dependent dynamic stability is very important factor to obtain excellent electro-optic characteristics such as high transmittance and low driving range.[17]

Figure 3 shows the measured voltage-dependent transmittance (V–T) characteristics for the proposed cell structure. As already mentioned, we used the LC with negative dielectric anisotropy to obtain the high transmittance characteristic. In the FFS mode, the electro-optic characteristics strongly depend on sign of dielectric anisotropy of the LC either positive or negative.[18] The operating voltage at which the maximal transmittance occurs is 5 V.

Finally, we performed ESD test in 2.0-in. quarter video graphics array (qVGA) LCD panel, which is designed with the proposed cell structure. Figure 4 shows the picture image of LCD after an applied ESD test. Figures 4(a) and 4(b) exhibit images for two cases: CrBM connected to the common electrode and the one not connected to the common

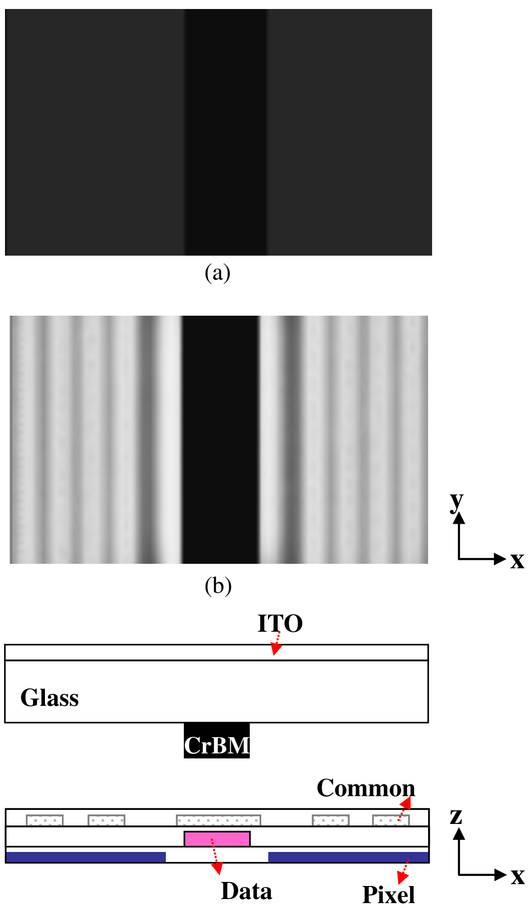

Fig. 2. (Color online) Transmittance characteristics of the proposed FFS-LCD at 300 V applied to the back-side ITO of top glass substrate: (a) dark state and (b) white state.

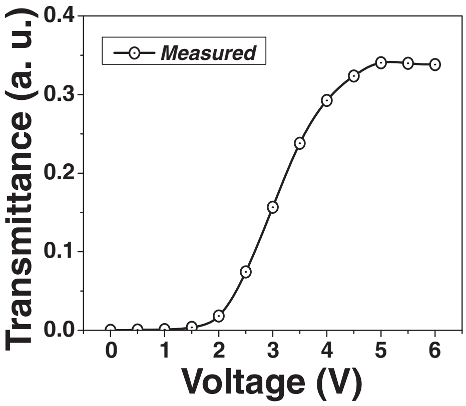

Fig. 3. Measured voltage-dependent curve.

(a) (b)

Fig. 4. (Color online) Picture image of LCD after an applied ESD test: (a) BM connected to the common electrode and (b) BM not connected to the common electrode.

electrode. For the test, we first contacted the discharging gun to the panel in which the protect layer was peeled off. Then, the panel was exposed to the high voltage of 8 kV by the discharging gun. In the first case, the device exhibited the stable dark state on a non-operation condition and also it showed good image quality even with operating conditions as shown Fig. 4(a). We also have checked V–T curves after ESD test and it shows the same V–T curves as in Fig. 3. On the other hand, the displayed image is totally distorted in the case that the CrBM is in floating state, as shown in Fig. 4(b). From this, we can once know that the CrBM connected to the common electrode perfectly discharge the electrostatic charges. The detailed ESD conditions were given in Table I. The measurement machine used is a Noiseken ESS 200AX.

Table I. ESD test condition (non-operation).

Capacitance (pF)	$150 \pm 10\%$
Resistance (Ω)	$330 \pm 5\%$
Voltage (kV)	0 ± 6
Discharging number	5
Type	Contact

3. Summary

In summary, we proposed the static electricity resistant FFS-LCD. The structures and performances of the proposed LCD were investigated by a commercial 3D LC simulator and experiments. In the proposed LCD, the CrBM in the top glass substrate is connected to the common electrode on the bottom substrate by the Ag transfer dotting and also the common electrode also contacts to border chassis. Consequently, the high image quality of the FFS-LCD can be kept even under a very high electrostatic voltage on top surface of the display.

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