Simulation of Pixel Voltage Error for a-Si TFT LCD Regarding the Change in LC Pixel Capacitance

Yongfu Zhu, Muju Li, Jianfeng Yuan, Chuanzhen Liu, Bailiang Yang, and Dezhen Shen

***Abstract*—LC pixel capacitance C_{lc}, which changes with the director of liquid crystal molecules as a function of external applied voltage, has a most important impact on the pixel voltage error ΔV_p and therefore on the electro-optics (E-O) characteristics of LC pixel for a-Si TFT LCD. In this paper, the pixel voltage error has been simulated for 10.4″ VGA (640×480) and SVGA (800×600) a-Si TFT LCD, and in this simulation, we especially took into account the change in LC dielectric constant. We found that ΔV_p changes with the data voltage V_p. In addition, E-O characteristics of LC pixel for a-Si TFT LCD has been investigated. The result shows that the effect of ΔV_p on E-O characteristics is significant when V_p ranges from the threshold voltage to the saturation voltage.**

***Index Terms*—Electro-optical characteristics, liquid crystal capacitance, liquid crystal displays, thin-film transistor, voltage error.**

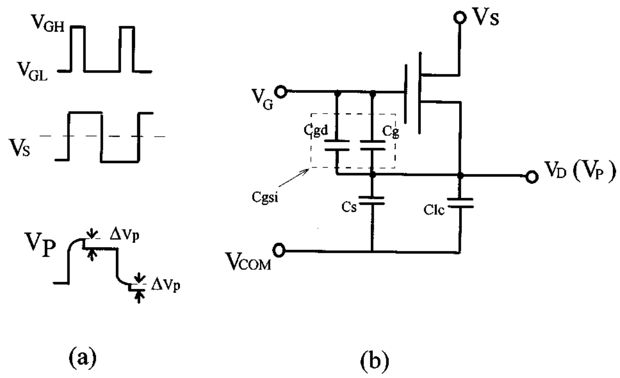

Fig. 1. Schematic diagram of the driving waveform and the equivalent circuit of LC pixel for a-Si TFT LCD.

I. Introduction

Amorphous-silicon thin-film transistors (a-Si TFT) are of considerable interest for applications involving large-area active matrix-addressed liquid crystal displays (AM-LCD). Though a great progress has been made in a-Si TFT AM-LCD, the study of some subjects remains active to improve the performance.

When a-Si TFT is turned off at the end of a charging period, there is a voltage error ΔV_p induced on the pixel electrode. The voltage error ΔV_p is a serious problem to large area and high-resolution a-Si TFT LCD because it results in the electro-optics (E-O) characteristics error, which leads to display deterioration such as flickers [1], shadings [2], and gray scale error [3].

Papers have been presented to discuss ΔV_p to solve this problem [4]–[6]. Some suggest that ΔV_p is induced by the crossover capacitance C_{gd} due to overlaps between the gate and the drain electrode of TFT, and that ΔV_p is independent on the data voltage V_p. However, replacing the LC pixel capacitance by a constant capacitor, the experiment [7] showed that ΔV_p is linear with V_p. This result can be explained if the channel capacitance C_g is included [8]. Theoretic work [9] also proved that ΔV_p depends evidently on the channel capacitance C_g between the channel at the source side and gate electrode.

Though much research work has been devoted in this area, there has been no a clear interpretation for voltage error ΔV_p. As we know, the LC director changes with the external applied voltage, and this produce a change in LC capacitance. However, this factor was neglected in previous work. In this paper, by taking into account this change, the voltage error ΔV_p and E-O characteristics of LC pixel have been simulated for 10.4″ VGA and SVGA a-Si TFT AM-LCD.

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II. The Capacitance in Circuits for LC Pixel of A-Si TFT LCD

The schematic diagram of the driving waveform and the equivalent circuit for LC pixel of a-Si TFT LCD is shown in Fig. 1. When the gate pulse changes from V_{GH} to V_{GL}, there is a decrease ΔV_P in the drain pixel voltage V_p referring the ON state of a-Si TFT. The capacitance in this circuit includes the crossover capacitance C_{gd}, the storage capacitance C_s, the channel capacitance C_g, and the LC capacitance C_{lc}. Here, we define C_{gsi} as the combination of C_{gd} and C_g. C_{gsi} is the total of C_{gd} and a half of C_g when a-Si TFT is on, thus C_{gsi} referring ON and OFF state of a-Si TFT can be expressed as [8]

$$C_{\mathrm{gs\,on}} = C_{gd} + \frac{C_g}{2} \qquad \text{ON STATE} \tag{1}$$

$$C_{\mathrm{gs\,off}} = C_{gd} \qquad \text{OFF STATE} \tag{2}$$

respectively.

The storage capacitor plays the role to eliminate the pixel voltage error, and its area is one of the main factors determining the aperture ratio of a-Si TFT array.

The director of liquid crystal changes with external applied voltage, and this result in a change in the LC dielectric constant and therefore in the LC capacitance. According to Oseen–Frank continuum theory, Ling *et al.*simulated the configuration of

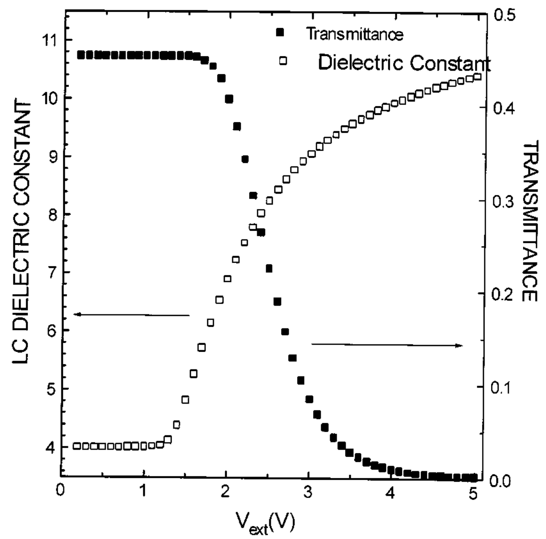

Fig. 2. LC dielectric constant and transmittance as a function of various external applied voltage.

liquid crystal director and E-O characteristics under different external applied voltage for passive matrix LCD [10]. To obtain the effective LC dielectric constant under various voltages V_p, the whole cell is divided into 100 layers. Then based on the work of Ling *et al.*, we get the LC dielectric constant of every single layer. Finally, the effective dielectric constant value of LC pixel under different external applied voltages can be obtained. Together with E-O characteristics, the effect of the external applied voltage V_{ext} on the LC dielectric constant is shown in Fig. 2.

III. Model

As described above, the alternation between ON and OFF state of a-Si TFT leads to a voltage error ΔV_p for LC pixel, and it then results in a slight change in LC dielectric constant. According to the law of conservation of electric change, we have

$$(V_p - V_{com})(C_{\mathrm{lc\,on}} + C_s) + (V_p - V_{GH})C_{\mathrm{gs\,on}} = (V_p' - V_{com})(C_{\mathrm{lc\,off}} + C_s) + (V_p' - V_{GL})C_{\mathrm{gs\,off}} \quad (3)$$

$$V_p' = V_p - \Delta V_p \quad (4)$$

where

$C_{\mathrm{lc\,on}}, C_{\mathrm{lc\,off}}$	LC pixel capacitance referring ON and OFF state of a-Si TFT, respectively;
V_{COM}	voltage of common electrode;
V_p	data voltage, i.e., the LC pixel voltage referring ON state of TFT;
V_p'	LC pixel voltage referring OFF state of TFT.

So, ΔV_p can be taken from (1)–(4):

$$\Delta V_p = \frac{(V_{com}-V_p)(C_{\mathrm{lc\,on}}-C_{\mathrm{lc\,off}})+\Delta V_g C_{gd}+(V_{GH}-V_p)C_g/2}{C_{gd}+C_{\mathrm{lc\,off}}+C_s} \quad (5)$$

TABLE I
PARAMETERS OF a-Si TFT LCD USED IN THE SIMULATION

Parameter	Value
Channel area (μm^2)	1000
Dielectric constant of a-SiN_x	6.9
Thickness of a-SiN_x layer(nm)	400
LC cell gap(μm)	5
On state gate voltage(V)	15
Off state gate voltage(V)	-5
Common electrode voltage(V)	5
Area of crossover capacitance (μm^2)	300

where

$$C_{\mathrm{lc\,off}} = \varepsilon_o \varepsilon_{\mathrm{off}} s_{\mathrm{lc}}/d_{\mathrm{lc}}$$
$$C_{\mathrm{lc\,on}} = \varepsilon_o \varepsilon_{\mathrm{on}} s_{\mathrm{lc}}/d_{\mathrm{lc}}$$
$$C_g = \varepsilon_o \varepsilon_i s_{\mathrm{TFT}}/d_i$$
$$C_{gd} = \varepsilon_o \varepsilon_i s_{gd}/d_i$$
$$C_s = \varepsilon_o \varepsilon_i s_s/d_i$$
$$\Delta V_G = V_{GH} - V_{GL}$$

where

ε_o and ε_i	vacuum dielectric constant and the dielectric constant of a-SiN_x;
s_{lc}	area of the LC pixel;
s_s	area of the storage capacitance;
s_{TFT} and s_{gd}	the area of TFT channel and the crossover capacitance, respectively;
d_{lc} and d_i	the LC gap and the thickness of insulator layer, respectively,
$\varepsilon_{\mathrm{on}}$ and $\varepsilon_{\mathrm{off}}$	LC dielectric constant referring ON and OFF state of TFT, respectively;
V_{GH} and V_{GL}	ON-state and OFF-state gate voltage of TFT, respectively.

IV. Results and Discussion

A. Voltage Error for the Pixel Electrode

The parameters of a-Si TFT LCD array used in the calculation are summarized in Table I. Applying the LC dielectric constant as a function of the external applied voltage to formulation (5), we obtained the dependence of ΔV_p on data voltage V_p for 10.4″ VGA and SVGA a-Si TFT AM-LCD in Fig. 3. When V_p is below the threshold voltage, for a-Si TFT LCD without C_s-design, there is a slight increase in ΔV_p, and in contrast, in the case that C_{st} is adopted, as means a reduction in the aperture ratio, there is almost no change in ΔV_p. When V_p ranges from the threshold voltage to the saturation voltage, ΔV_p decreases abruptly with V_p. If V_p is over the saturation voltage, ΔV_p increases very slowly.

For 10.4″ TFT LCD with the same resolution, the higher the aperture ratio is, the higher ΔV_p is. On the other hand, for 10.4″ a-Si TFT LCD with the same aperture ratio, ΔV_p for SVGA is higher than that for VGA, as is clearly shown from the comparison of Fig. 4(a) and (b).

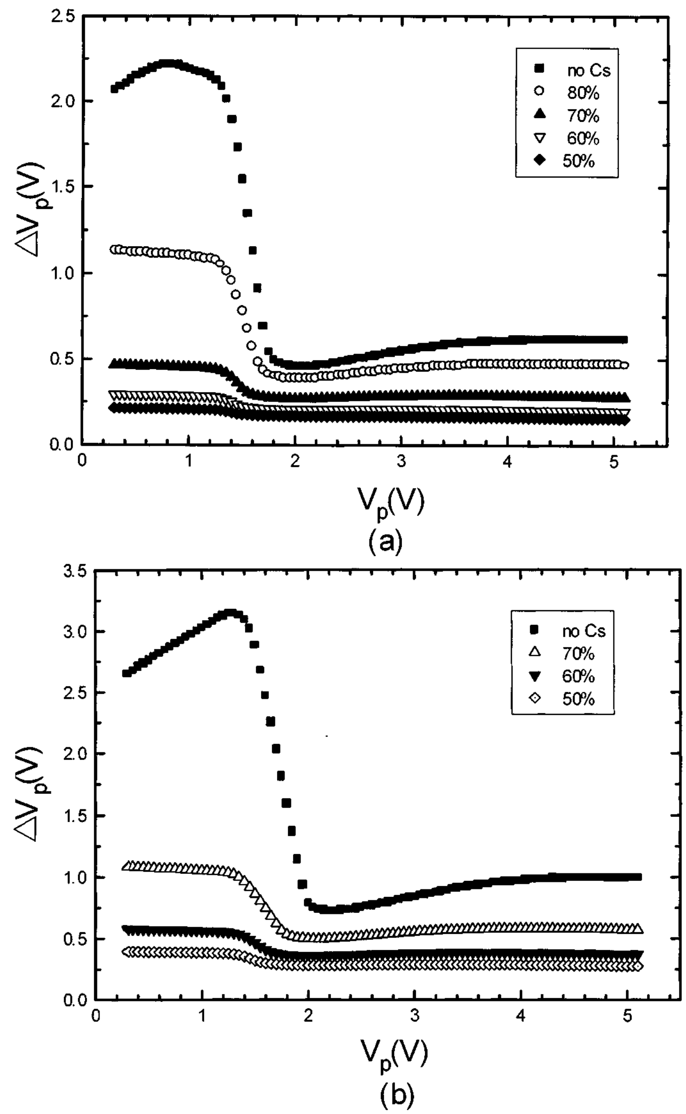

Fig. 3. Pixel voltage error as a function of data voltage for 10.4″ a-Si TFT LCD with various aperture ratio. (a) VGA, and (b) SVGA.

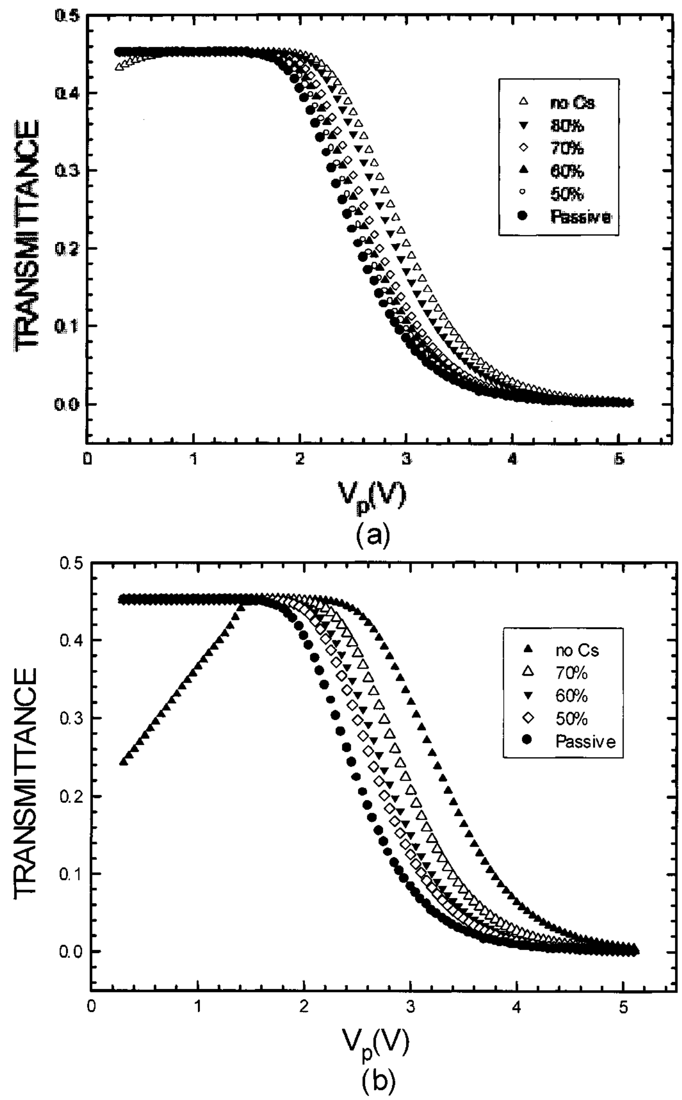

Fig. 4. E-O characteristics for 10.4″ a-Si TFT LCD with various aperture ratio. (a) VGA, and (b) SVGA.

B. E-O Characteristics for LC Pixel

E-O characteristics for LC pixel of 10.4″ VGA and SVGA a-Si TFT LCD with various aperture ratio is shown in Fig. 4. As a contrast, E-O characteristics for passive matrix LCD given in Section II is also provided. We found that there is a discrepancy in E-O characteristics between a-Si TFT LCD and the passive matrix LCD. In either full on-state or full off-state of LC pixel, the discrepancy is negligibly small, but it became evident when V_p is within the region between the threshold voltage and the saturation voltage.

Similar to ΔV_p, for 10.4″ TFT LCD with the same resolution, the higher the aperture ratio is, the more significant the discrepancy is. On the other hand, the comparison of Fig. 4(a) and (b) shows the discrepancy for SVGA a-Si TFT LCD is more significant than that for VGA a-Si TFT LCD when the aperture ratio is the same. Here, we especially notice that, for SVGA without C_s-design, even though V_p is below the threshold voltage, the false signal appears due to the rotation of liquid crystal molecules caused by ΔV_p.

As we know, the discrepancy in E-O characteristics is caused by the voltage error ΔV_p, and this discrepancy will result in deterioration in gray scale. When the data voltage V_p is below the threshold voltage of LC pixel, though ΔV_p is high, the discrepancy is not significant except SVGA a-Si TFT LCD without C_s-design. While V_p ranges from the threshold voltage to the saturation voltage, ΔV_p decreases abruptly, and the discrepancy is significant. In the full on-state of LC pixel case, ΔV_p is low, and a slight increase could be seen in ΔV_p. The result suggests that the discrepancy in E-O characteristics is not proportional to ΔV_p, and ΔV_p will have evident impact on the E-O characteristics when the data voltage V_p ranges from the threshold voltage to the saturation voltage of LC pixel.

V. CONCLUSION

In summary, the pixel electrode voltage error and E-O characteristics for 10.4″ VGA and SVGA a-Si TFT have been simulated regarding the change in LC dielectric constant. The results show that ΔV_p changes with the data voltage V_p and that ΔV_p

affects E-O characteristics evidently when V_p is within the region between the threshold voltage and the saturation voltage.

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