

ELECTRO-OPTICAL SIMULATION OF a-Si THIN-FILM-TRANSISTOR LIQUID-CRYSTAL DISPLAY PIXELS

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ABSTRACT: An analysis of an amorphous silicon (a-Si) thin-film-transistor liquid-crystal display (TFT-LCD) pixel is presented. The electro-optical model combines the electrical properties of the switching element and the optical performance of a twisted nematic (TN) liquid-crystal cell.

Key words: electro-optical model; thin-film transistor; twisted nematic cell; liquid-crystal displays; optical performance

1. INTRODUCTION

Active matrix (AM) addressing is a technique employed to enhance the addressing and driving of dot-matrix liquid-crystal displays (LCDs). As is known, AM addressing is achieved by placing active elements (transistors or diodes) on the display inner surface, so that each individual pixel is driven by an element. The main advantage of this addressing method is that LCD addressing and writing become separate processes [1]. Indeed, every row can be written very rapidly; the written information is kept by the active element, while the remaining rows are addressed. Needless to say, the hardware required by this addressing method is more complex than regular passive matrices because each LCD pixel must include a switching element. Nevertheless, noticeable improvements in terms of the LCD optical performance are achieved with this approach.

Although a number of switching elements have been proposed, the thin-film transistor (TFT) has emerged as the most promising device due to its peculiar electrical properties and reasonable manufacturing yield. TFT-LCD is a mature technology nowadays. In fact, it is ubiquitously produced around the world [2]; a remarkable production increment is expected in the coming years.

Up to three materials have been proposed for TFT manufacturing: amorphous silicon (a-Si), polysilicon (p-Si), and cadmium selenide (CdSe). At present, the third alternative has been almost abandoned. Although it is known that p-Si gives superior performance [3], a-Si is currently preferred because the manufacturing process of p-Si requires higher temperatures, unsuitable for regular glasses—thus requiring relatively expensive substrates (e.g., silica).

In this paper, an electro-optical model of an LCD pixel driven by an a-Si TFT is presented. The model intends to include every feature of the actual device. Specifically, a storage capacitor must be added to each pixel in order to improve the image quality. This complicates the transistor design and manufacturing because the charging process requires the TFT to be relatively large. Thus, the light through-

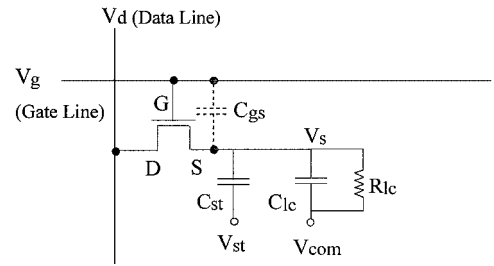


Figure 1 Simple equivalent circuit of an a-Si TFT/LCD pixel

put across the pixel—as measured by the aperture ratio—is reduced, impairing its optical properties.

2. ELECTRICAL MODEL OF AN a-Si TFT

Figure 1 shows a simple equivalent circuit of a pixel attached to a TFT device that includes a parasitic capacitor (C_{gs}), the capacitance associated with liquid-crystal cell and voltage signals for data and gate lines. An additional storage capacitance C_{st} is included to avoid the voltage drop due to leakage currents.

When a file selection pulse V_g is applied, the voltage in the TFT source (V_s), for a given data signal (V_d), can be obtained by solving the following equation [4]:

$$\frac{dV_s}{dt} = \left(\frac{1}{2}\right) \left(\frac{\beta_0}{C_{px}}\right) \left[(V_g - V_t - V_s)^2 - (V_g - V_t - V_d)^2 \right] \quad (1)$$

where V_t is the threshold voltage of TFT, C_{px} is the sum of capacitors ($C_{lc} + C_{st} + C_{gs}$), and β_0 is a characteristic constant of the TFT.

Figure 2 shows the resulting waveforms for V_d , V_g , and V_s , assuming that the time elapsed for the pixel to discharge is much larger than the display framerate. In other words, the pixel voltage is assumed to be constant along the whole frame. It can be seen that V_s is modified upon V_g transitions, due to the presence of C_{gs} . These variations can be compensated by adjusting the voltage in the common electrode (V_{com}).

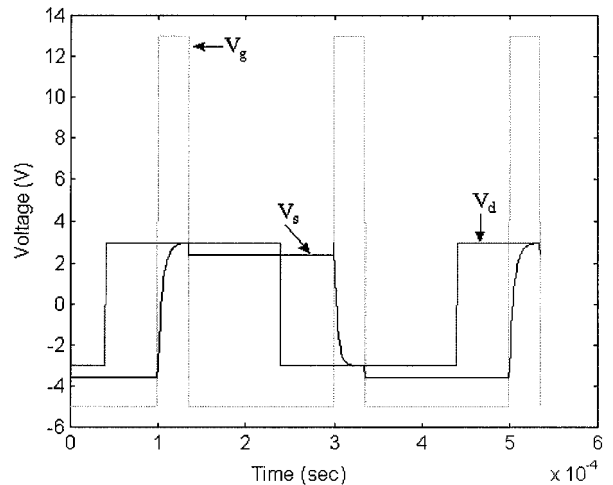


Figure 2 Pixel voltage waveforms for an AM-LCD using an a-Si TFT

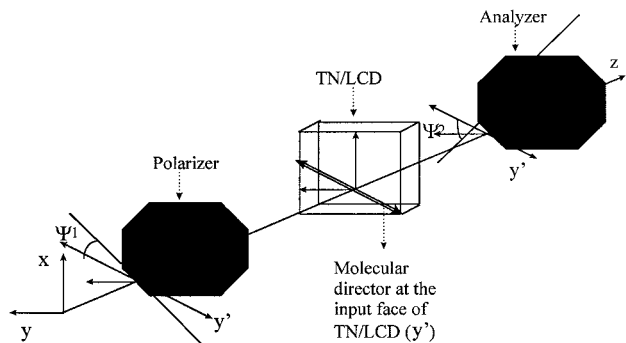


Figure 3 Coordinate system and angles used in the optical model

3. OPTICAL MODEL OF A LIQUID-CRYSTAL PIXEL

The optical model is based on the usual twisted nematic (TN) configuration of most TFT-LCDs. The geometrical parameters of this setup are shown in Figure 3. The electric field transmitted by a TN device can be calculated by Jones algebra [5] as follows:

$$E_0 = P_0 R(\psi_2) R(-\alpha) \text{TN}(\alpha, \beta) R(\psi_1) E_i. \quad (2)$$

ψ_1 and ψ_2 are the angles between the polarizer and analyzer axes and the molecular director at the cell entrance, E_i is the electric field of incident light, P_0 is the Jones matrix for the analyzer, and $R(\cdot)$ and TN are the rotation matrix and the matrix associated with the TN cell, respectively; α is the rotation of the birefringent LC axis across the device ($\approx 90^\circ$), β is the local LC birefringence, and γ is given by $[\alpha^2 + \beta^2]^{1/2}$.

4. ELECTRO-OPTICAL MODEL OF AN a-Si TFT-LCD PIXEL

An electro-optical model to characterize TFT pixels has been prepared by merging the two models described above [6]. Several features have been tested on the model. For example, Figure 4 shows the evolution of the response, and the pixel capacitance ($C_{lc} + C_{st}$) is increased. Sixteen gray levels can be obtained in this case.

5. CONCLUSIONS

An electro-optical model describing TFT-LCD pixels has been presented. The model allows the computation of the data signals required for the desired gray scale to arise. Optical variations due to a number of electric parameters can also be observed.

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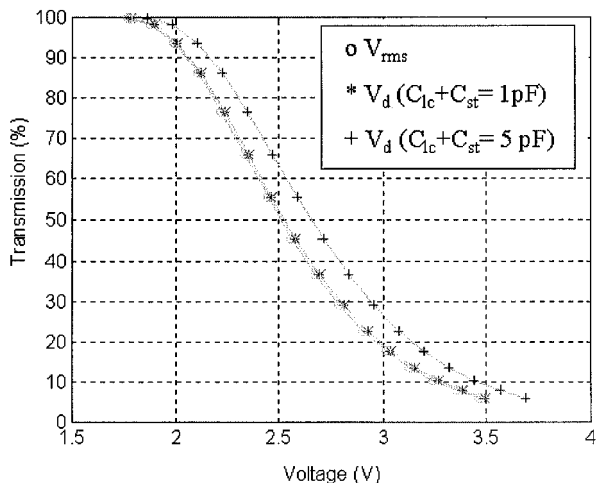


Figure 4 Simulated gray scale as a function of V_{rms} and V_d for different values of pixel capacitors