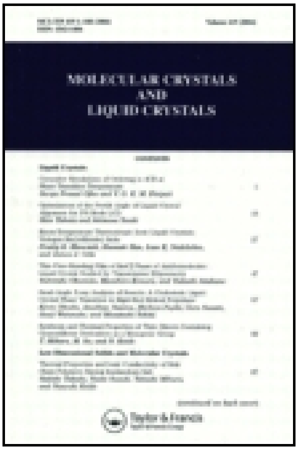

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Low-Power Operation of an Image-Memory LCD using Ferroelectric Film

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The authors have proposed an image-memory LCD using ferroelectric thin film for memory elements to achieve ultralow power consumption. Memory operation with gray-scale levels was confirmed by using an equivalent circuit model of the LCD consisting of a discrete ferroelectric device. The reduction in power consumption is related to hold time and the ferroelectric characteristics.

Keywords: image-memory LCD; low power consumption; ferroelectric film

INTRODUCTION

Low-power LCDs are increasingly required as a result of the growing need for information to be displayable anywhere and at any time. The driving power consumption of a reflective LCD can be reduced by implementing a memory function for each pixel. We have proposed a novel memory element using a ferroelectric thin-film with gray-scale capability[1][2] to solve problems encountered in the case of previous

LCDs, namely SSFLC[3], cholesteric LCD[4], and AM-LCD with memory circuits[5], which are binary-state, low response time, low resolution, low light efficiency, and so on. In this paper, the authors report a low-power operation of the image-memory LCD that has been investigated by simulated experiments.

IMAGE-MEMORY LCD USING FERROELECTRIC FILM

In the concept of the proposed image-memory LCD, the ferroelectric polarization holding the image data is used to influence the molecular alignment of the liquid crystal layer. Figure 1 shows the basic schematic structure of the proposed image-memory LCD. The electric field generated by the fixed charge on the surface of the polarized ferroelectric film is applied to the liquid crystal layer. The spontaneous polarization of the ferroelectric film is memorized for a long time and the resistivity of the ferroelectric film and the liquid crystal are sufficiently high because both are insulators, and therefore the alignment of the liquid crystal can be maintained for a certain period.

By using an inorganic ferroelectric, high addressing speed can be obtained, and so this satisfies the demand for display of moving images. The simple structure is highly advantageous for realizing high resolution. From these features of the proposed image-memory LCD, an attractive device such as an electric paper with multimedia content can be realized.

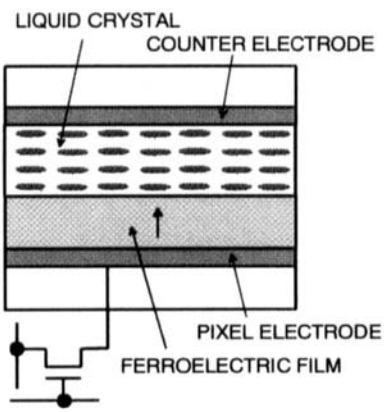

FIGURE1 Schematic structure of the proposed image-memory LCD.

Equivalent Circuit Model

The proposed image-memory LCD can be treated electrically by an equivalent circuit which consists of a liquid crystal capacitance, Clc, and a ferroelectric capacitance, Cf, as shown in Figure 2. In order to investigate actual operation of the image-memory LCD, the equivalent circuit model which consists of a discrete inorganic ferroelectric device (PZT capacitor) and a constant capacitor for the liquid crystal layer was used.

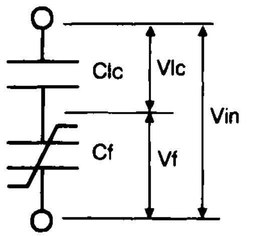

FIGURE 2 Equivalent circuit model of the image-memory LCD.

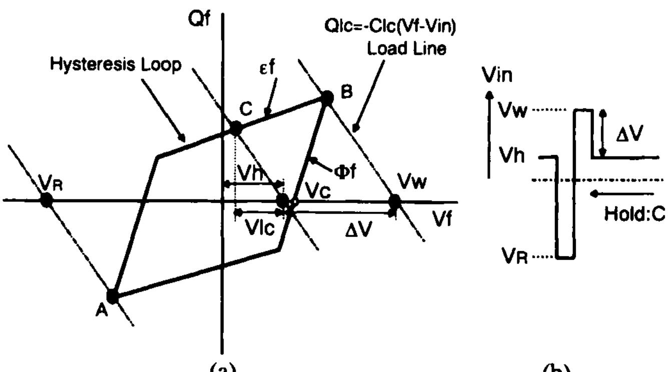

FIGURE 3 Operating points on the Q-V hysteresis (a) and driving waveform (b).

Operation Principle

Figure 3 shows a Q-V hysteresis and operating points and the driving waveform. The operating point is obtained as a crosspoint between the hysteresis loop and a load capacitance line by charge conservation. The driving sequence has three stages: reset stage applying reset voltage, V_R, write one applying writing voltage, Vw, and hold one applying holding voltage, Vh.

The ferroelectric polarization can be controlled by applying input voltage to the circuit. After the reset stage, writing voltage is applied and the operating point moves to point B, so that the ferroelectric film has a certain polarization, Pf. The polarization can be maintained when the input voltage is down to the holding voltage, and then, finally, an output voltage shown as Vlc is applied to the liquid crystal.

The voltage ΔV, which is the difference between Vw and Vh, shows a writing signal voltage corresponding to polarization which we want to control. Vc shows the coercive voltage and it is the basis of the voltage value used in this work.

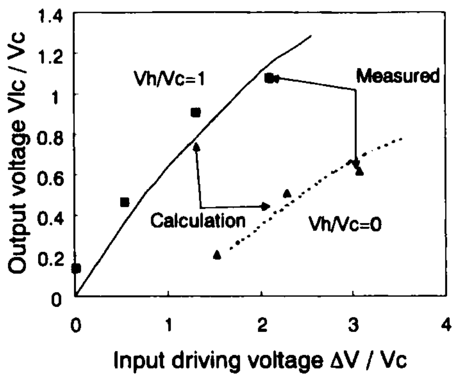

FIGURE 4 Experimental and theoretical input voltage-output voltage relationships of the equivalent circuit model.

<u>Input-Output Relationships</u>

Figure 4 shows the relationships between the input signal voltage, ΔV, and the output load capacitance voltage, Vlc. The plots represent the measured values. It is confirmed that the value of the output holding voltage can be changed by applying a certain input voltage, which means the gray-scale image can be obtained by this operating method.

Moreover, when the hold voltage, Vh, increases, the ratio of input-output voltage can be improved, and thus a signal driver circuit with low operating voltage could be adopted.

The lines represent the values calculated by operating point analysis on the measured Q-V hysteresis. The experimental data coincide with the theoretical lines, and therefore the output voltage can be predicted from hysteresis measurement.

Holding Characteristics

Figure 5 shows the output voltage dependence on the holding time after applying one writing pulse. It is found that the output voltage is maintained for over 40min. This means the used ferroelectric device has sufficiently high resistance. The holding characteristics are almost the same in the case of two different writing voltages. Therefore, it has been electrically confirmed that the memory operation can be obtained with gray-level.

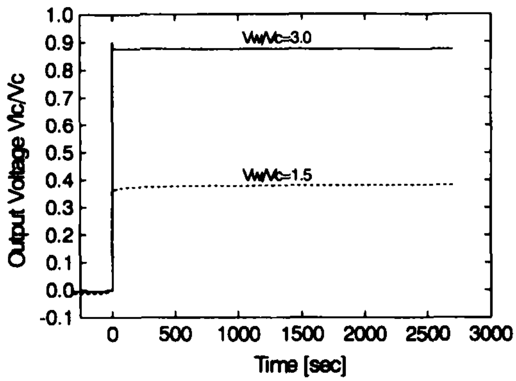

FIGURE 5 Holding characteristics of the equivalent model after one pulse writing at the different writing voltage.

Power Consumption Reduction

Driving power consumption of the image-memory LCD is related to the driving voltage and the holding time. When a capacitance C is charged and discharged at voltage V and a frequency f, power consumption P is obtained by following equation:

$$P = CfV^2 \quad (1)$$

The driving voltage is related to the hysteresis shape. When the hysteresis loop is assumed to be a parallelogram, we define a hysteresis shape parameter, $\Phi f/\varepsilon f$, as the ratio of a large slope and a small slope. The minimum driving voltage can be obtained as a function of the hysteresis shape parameter. Then, the power consumption under a certain holding time can be calculated.

When the hysteresis shape parameter increases, the hysteresis loop becomes approximately a square and the input voltage can be reduced to the same voltage as the output voltage. Under an optimized driving voltage condition, the relationship between power consumption ratio including a reset process and holding time has been simulated as shown in Figure 6. For the discrete ferroelectric device, whose Φf/εf is evaluated to be ~10, the optimized power consumption can be estimated to be 1/10 for one-second holding, and extremely low at 10^{-4} for 10^{3} sec holding.

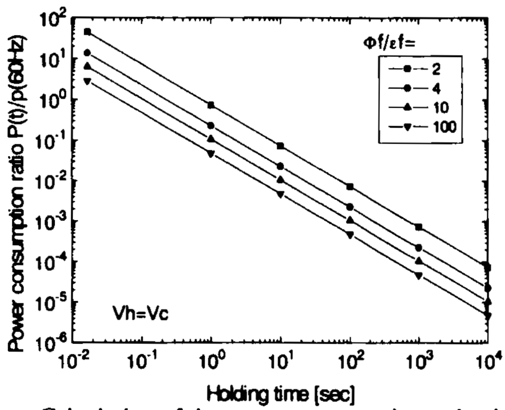

FIGURE 6 Calculation of the power consumption reduction due to the image-memory LCD under optimized driving.

CONCLUSION

An image-memory LCD using a ferroelectric film has been proposed. Using an equivalent circuit model with an inorganic ferroelectric discrete device, a memory operation with gray-scale levels has been confirmed and the power consumption is estimated to be extremely low for long-time holding. If the hysteresis shape parameter is 10, realized by an actual ferroelectric device, power reduction is 1/100 for 10-second holding. By developing low temperature formation technology of a ferroelectric film, the image-memory LCD could be realized on the glass substrate and widely used for various portable devices.

Acknowledgment

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