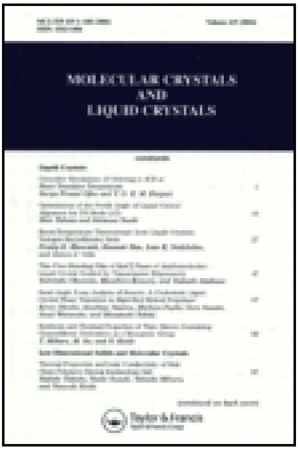

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Masami Yoshiyama [a], Tamotsu Matsuo [a], Kiyohiro Kawasaki [a], Hiroshi Tatsuta [a] & Takeshi Ishihara [a]

[a] Central Research Laboratories, Matushita Electric Industrial Co., Ltd., Moriguchi, Osaka, 570, Japan

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Small Liquid Crystal Television Display†

MASAMI YOSHIYAMA, TAMOTSU MATSUO, KIYOHIRO KAWASAKI, HIROSHI TATSUTA and TAKESHI ISHIHARA

Central Research Laboratories, Matsushita Electric Industrial Co., Ltd., Moriguchi, Osaka, 570, Japan

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A 2.4-inch reflective liquid crystal television display has been developed using an integrated liquid crystal matrix panel with 57,600 (240 × 240) picture elements. The panel incorporates a 240 × 240 array of active control elements fabricated on a silicon substrate.

The liquid crystal materials developed is the dynamic scattering type, and a nematic mixture of Schiff's bases and aromatic esters conductively doped with redox-type dopants for DC operation.

Real time television images with a resolution high enough for a small screen can be clearly displayed on the panel without defects under ordinary ambient lighting.

Small size (118 × 114 × 38 W · H · D mm), light weight (640 grams), and low power consumption (1.5 watt) are attained by using CMOS circuitry and high density mounting.

INTRODUCTION

Reflective liquid crystal displays have the following attractive features for small television displays.

(1) Low power consumption suitable for battery operation.

(2) Low drive voltage compatible with CMOS drivers.

(3) Good viewability under severe ambient light conditions.

These characteristics make it possible to construct a small battery-operated television display. In a liquid crystal matrix display with a large number of picture elements, there is multiplexing limitation. To overcome this problem, a number of integrated liquid crystal matrix panels have been proposed that incorporate a control element in series with a liquid crystal cell at each matrix

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point.[1-5] In such panels, MOS field effect transistors (FETs) or thin film transistors (TFTs) are used as active control elements, for example.

This paper describes a developmental small liquid crystal television display using an integrated liquid crystal matrix panel with active control elements. The liquid crystal material, the structure and characteristic of the panel, and performance of the television display are also described.

2 INTEGRATED LIQUID CRYSTAL MATRIX PANEL

2.1 Panel structure

Figure 1 shows a schematic structure of the integrated liquid crystal matrix panel developed. The panel has a structure in which a liquid crystal layer is sandwiched between a front glass plate with a transparent common electrode and an IC array. The IC array is a 240 × 240 array of control elements each of which comprises a switching MOSFET, a storage capacitor, and a reflecting electrode, and is fabricated by MOS technology on a silicon substrate. The IC array, which is often considered to be very difficult to fabricate without defects, is made in relatively high yield from 3-inch silicon wafer by using an improved photo-process technology. The liquid crystal used is the dynamic scattering type. Alignment of the liquid crystal is parallel to the electrode surfaces. The reflecting electrode is used as the common electrode for both the liquid crystal cell and the capacitor in one picture element, and also acts as a mirror for scattered light in the liquid crystal cell.

Figure 2 is a micro-photograph of a part of the IC array. The size of one picture element is 150 × 200 μm.

The integrated liquid crystal matrix panel developed has a reflective black and white screen with 57,600 (240 × 240) picture elements. Effective screen size is 36 × 48 mm, giving a diagonal dimension of 2.4 inches.

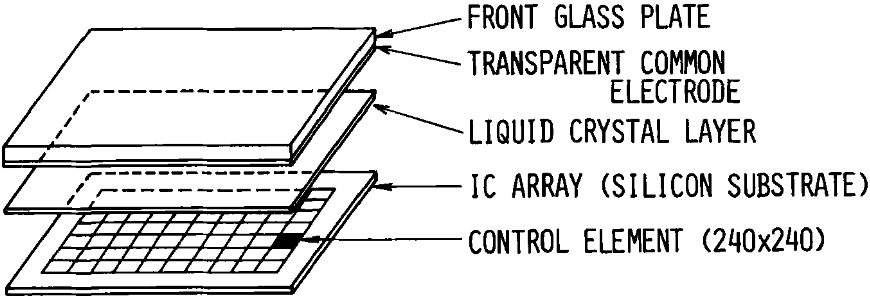

FIGURE 1 Schematic structure of an integrated liquid crystal matrix panel.

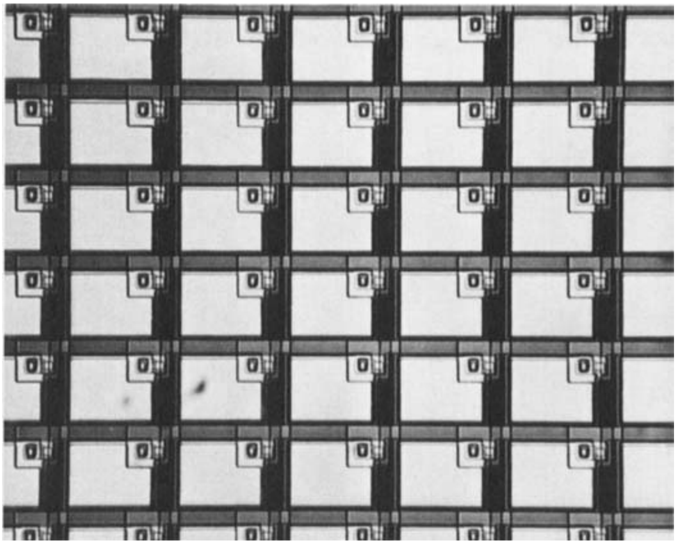

FIGURE 2 Micro-photograph of a part of an IC array.

2.2 Liquid crystal material

In the small liquid crystal television display, dynamic scattering is used as an operation mode of the liquid crystal. The dynamic scattering mode of operation does not require polarizers and has the following features preferable for reflective liquid crystal television displays: (1) High display brightness, (2) Colorless, black and white display, (3) Relatively wide viewing angle.

To attain low power consumption in the television display, DC operation is required for the liquid crystal material. A nematic mixture of Schiff's bases and aromatic esters has been developed as the liquid crystal material. This nematic mixture is doped with redox dopants,[6-7] in order to improve DC dynamic scattering characteristics. The dopant developed is a ternary system consisting of quinone derivatives and dihydric phenol derivatives. The nematic mixture has a nematic range of $-10°$ to $66°$C, and is homogenously aligned by rubbing of the electrode surfaces. Resistivity of the nematic mixture is prepared in a range of 3 to 4×10^9 ohm·cm.

The reflecting aluminum electrode surfaces are coated with indium tin oxide by sputtering, in order to improve the life of the panel for DC operation and the alignment of the nematic mixture.

Figure 3 shows a typical scattered light intensity vs. applied DC voltage characteristic of the nematic mixture in reflective cells. The maximum scattered light intensity is measured approximately twice as large as that of the standard white plate.

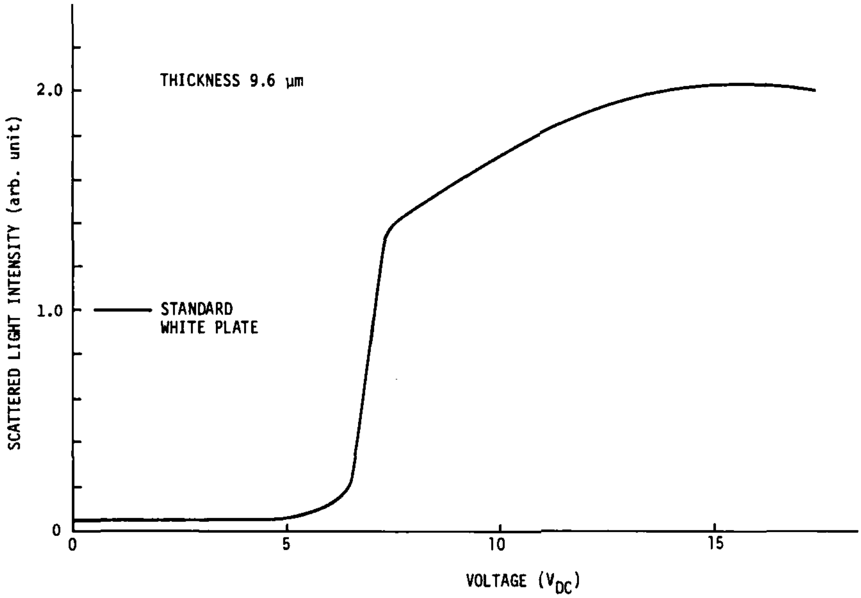

FIGURE 3 Scattered light intensity vs. voltage characteristic for a reflective cell.

The threshold voltage V_{th} and the voltage V_{90} that produces 90% of the maximum scattering are 6.3 and 10.4 volts, respectively. These voltages can be controlled to some extent by changing the mixing ratio of Schiff's bases and aromatic esters in the nematic mixture.

Figure 4 shows a typical response time vs. applied DC voltage characteristic of the above reflective cells at room temperature. These characteristics in Figures 3 and 4 are measured by means of a photomultiplier with correction filter at an angle of 15 degrees with respect to incident light.

Life tests of the nematic mixture for the DC operation are being done by using the reflective cells with a combination of indium tin oxide (negative) and indium tin oxide coated aluminum (positive) electrodes.

Most of the samples under test have been successfully in operation for more than 5,000 hours with 20 volts DC continuously applied.

2.3 Characteristic of the panel

The driving system of the panel for the television display consists of a combination of line-at-a-time scanning and amplitude modulation under the use of DC bias.

Figure 5 shows an equivalent circuit of a picture element for this driving system. When a MOSFET is turned on by a scanning pulse from a Y-line, video signal V_d from an X-line is transferred to a capacitor. If a time constant

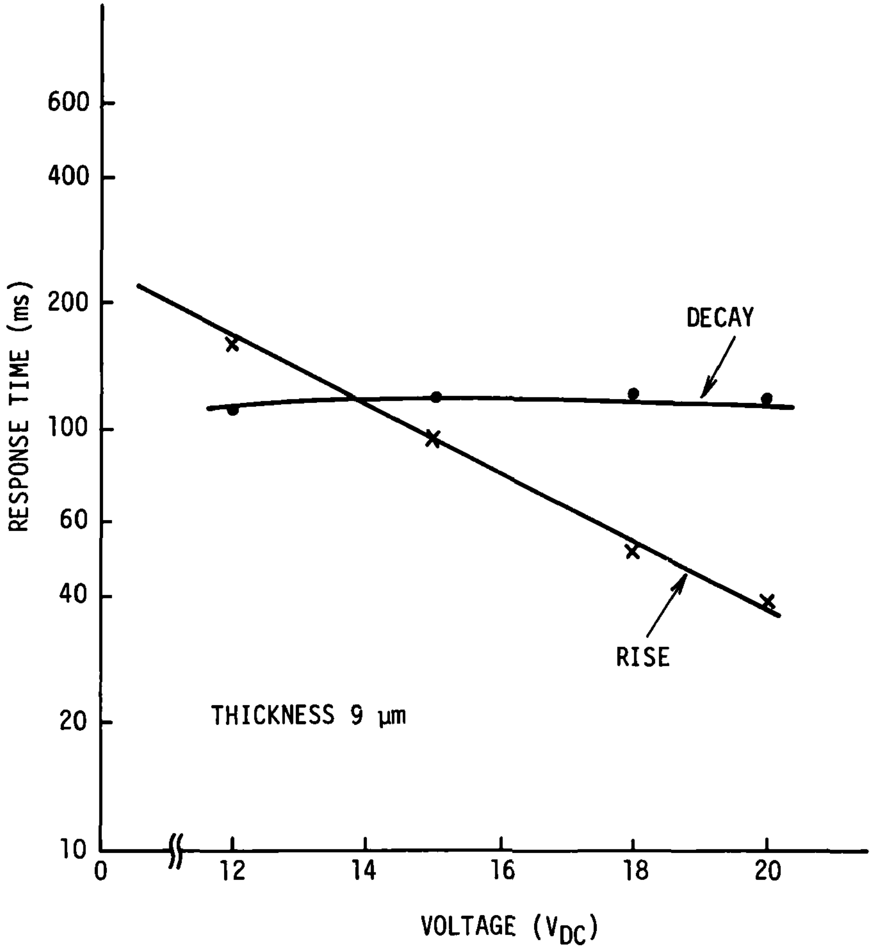

FIGURE 4 Response times vs. voltage characteristic for a reflective cell.

CR_L is sufficiently larger than one frame time (17 ms, 60 Hz), the capacitor is held nearly at the voltage level of V_d until next scan. As the DC bias V_C is applied to an LC cell, the scattered light intensity (brightness) of the picture element is modulated by the voltage difference $|V_c - V_d|$, and has, therefore, an inverse mode relationship to the video signal V_d, i.e. large scattering for no video signal and no scattering for a large video signal. However, there exists another resistive component R_p caused by photoconductive leakage in the silicon substrate. The photoconductive leakage through R_p is an undesirable effect which lowers the contrast of the displayed images.

This system is characterized by the incorporation of the DC bias V_c in order

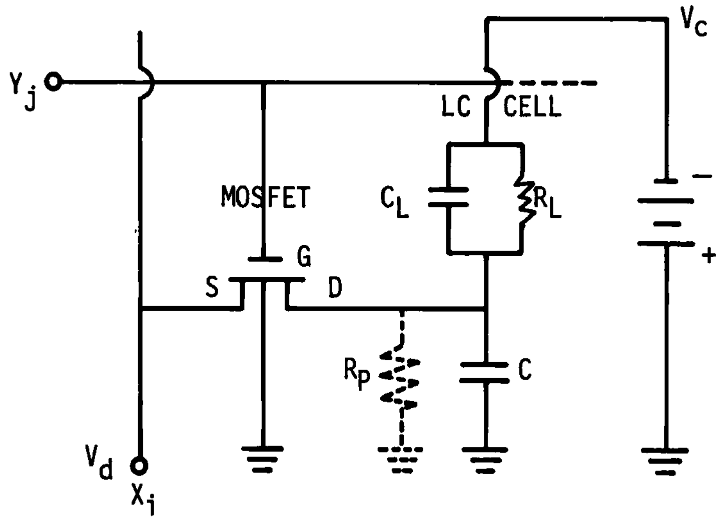

FIGURE 5 Equivalent circuit of one picture element for the television display.

to reduce the driving power consumption and to compensate the photoconductive effect.

In this system, a voltage drop in the capacitor caused by the photoconductive leakage through R_p is, to some extent, compensated by current from the DC bias V_c through R_L as shown in Figure 5.

Figure 6 shows the brightness modulation characteristic of the panel by the above driving system. The brightness is measured by a Prichard photometer at an angle θ with respect to the parallel light beam which is vertically incident on the panel. The brightness vs. video voltage characteristic under a given DC bias V_c is not the same for different viewing angles. The contrast ratio of 14:1 is measured at an angle of 15 degrees with respect to incident light.

3 RESULTS AND PERFORMANCE OF THE TELEVISION DISPLAY

Figure 7 is a photograph of the developmental small liquid crystal television display. The television display is shaped like a cigarette case, with a dimension of 118 (W) × 115 (H) × 34 (D) mm. It's weight and power consumption are 640 grams and 1.5 watt, respectively. In order to attain low power consumption, CMOS integrated circuitry is employed in the peripheral circuit. Miniaturization is attained by high density mounting of both the panel and the peripheral circuit on a thin ceramic plate. Key specifications and performance of the television display are summarized in Table I.

Figure 8 is an example of received image on the television display.

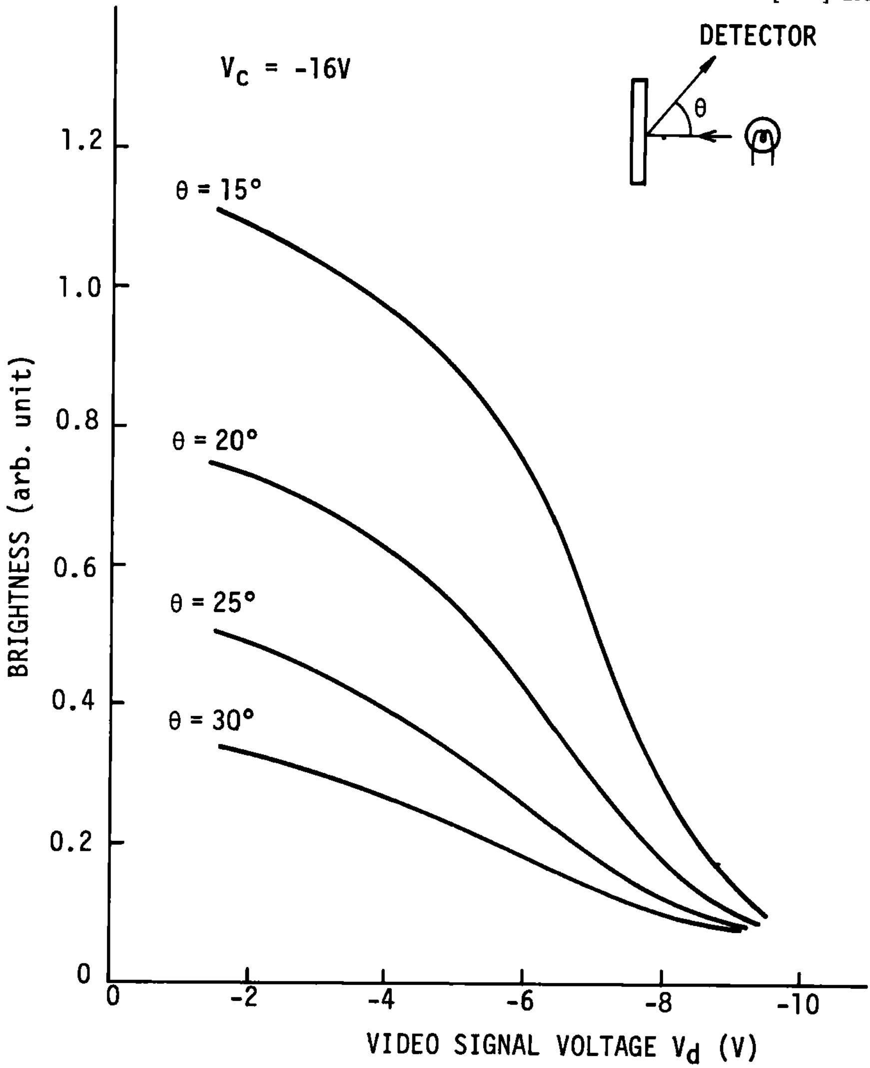

FIGURE 6 Brightness modulation characteristic of an integrated liquid crystal matrix panel, at DC bias $V_c = -16$V.

4 CONCLUSION

In the developmental small liquid crystal television display, real time black and white images can be clearly displayed under ordinary ambient light conditions, though effective viewing angle is restricted to a relatively narrow range.

1) The resolution of the displayed images is high enough for a small screen size.

FIGURE 7 Developmental small liquid crystal television display.

2) Fairly good uniformity is obtained over the whole displayed images without notable defects.

3) A few point defects seem to be acceptable, as long as they are randomly located. A line defect, however, is not acceptable, because the eye is very sensitive to it.

4) Smear is observed for very fast moving images.

FIGURE 8 Example of a received television image.

TABLE I

Summary of key specifications and performance

Display Type	Reflective-type, B/W
Display Panel	Integrated-type, 44 × 56 mm
Effective Screen	36 × 48 mm (2.4 inches)
Picture Element	57,600 (240 × 240), 150 × 200 μm
Liquid Crystal	DSM, Nematic mixture
Driving Mode	Line-at-a-time, 60 Hz
Brightness Mod.	PAM, DC bias
Contrast Ratio	14:1, ($\theta = 15°$)
Response Speed	Rise 60 ms, Decay 100 ms
Power Source	4.6V (with 2 batteries)
Power Consumption	1.5W (total)
Dimensions	118 × 115 × 34 W·H·D mm
Weight	640g (including batteries)

Further improvement is preferable in viewing angle, contrast ratio, response speed for commercial television displays.

The problems in producing the integrated liquid crystal matrix panel have been overcome by improvements in fabrication technology. Small size, light weight and low power consumption are attained by using CMOS circuitry and high density mounting.

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