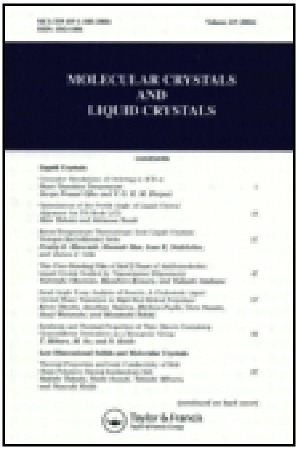

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Large-area Projection HAN-mode Multicolor TFT-addressed LCD†

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A liquid crystal multicolor projection display using a TFT-addressed hybrid-aligned nematic (HAN) cell without a color filter has been developed. Compared to a TFT color LCD with an RGB color filter, it has such advantages as five times brighter display and three times higher resolution.

1. INTRODUCTION

Various types of thin-film-transistor (TFT) addressed color LCDs using an RGB color filter have been reported.[1–4] However, when such color LCDs are applied to a projection display, some problems occur, *e.g.*, a poor brightness due to the low transmission of a color filter and a resolution loss due to that each color pixel is assigned RGB three pixels.

A hybrid-aligned nematic (HAN) LCD operated by an electrically controlled birefringence (ECB) effect has been applied to a multicolor projection display.[5] Liquid crystal molecules in a HAN LCD are aligned perpendicular to one substrate and parallel to the other. The HAN ECB LCD has the following advantages compared with other ECB LCDs; good color separation, bright color generation and low operating voltage. However, the conventional HAN LCD can display only either a multicolor fixed pattern on a bicolor flexible pattern by a conventional multiplexed matrix addressing.

A TFT-addressed HAN LCD (TFT-HAN LCD) has been recently developed.[6] It realizes a bright and high-resolution multicolor projection display using one TFT-addressed LC panel without a color filter. In this paper, its construction, electro-optical characteristics and display performance are described.

†Presented at The 1985 International Display Research Conference, San Diego, October 15–17, 1985.

2. PRINCIPLE OF A MULTICOLOR HAN LCD

Figure 1 shows a conceptional diagram of a HAN LCD. A HAN liquid crystal cell is placed between a cross or parallel polarizers and whose axes make an angle of 45 degrees with the liquid crystal director. The optical retardation between the ordinary and extraordinary rays passing through the LC layer is given by

$$\delta = \int_0^d \frac{n_e \cdot n_o \, dz}{(n_e^2 \cos^2\theta + n_o^2 \sin^2\theta)^{1/2}} - n_o d, \quad (1)$$

where n_o and n_e are the ordinary and extraordinary refractive indices of the liquid crystal, d is the cell thickness and θ is the local tilt angle of liquid crystal. The transmission of the LCD is given, depending on the polarizer arrangement, by

$$T(\lambda) \propto \sin^2(\delta \cdot \pi/\lambda) \quad \text{:cross polarizers} \quad (2)$$

$$T(\lambda) \propto \cos^2(\delta \cdot \pi/\lambda) \quad \text{:parallel polarizers} \quad (3)$$

The liquid crystal orientation is influenced by an applied voltage, due to a dielectric anisotropy of liquid crystal. So, the optical retardation changes depending on the value of applied voltage. Therefore, the transmission T(λ) is controlled by the applied voltage and the various color generation is achieved with changing the applied voltage. A display color with crossed polarizers is complementary to that with parallel polarizers.

Figure 2 shows an applied voltage dependence of optical retardation in a HAN cell, in case of a conventional static drive method. The birefringence $\Delta n(=n_e - n_o)$ is 0.12 and cell thickness d is 29 μm. The retardation was measured using a He–Ne laser beam (λ = 632.8 nm). In the same figure, a voltage dependence of optical

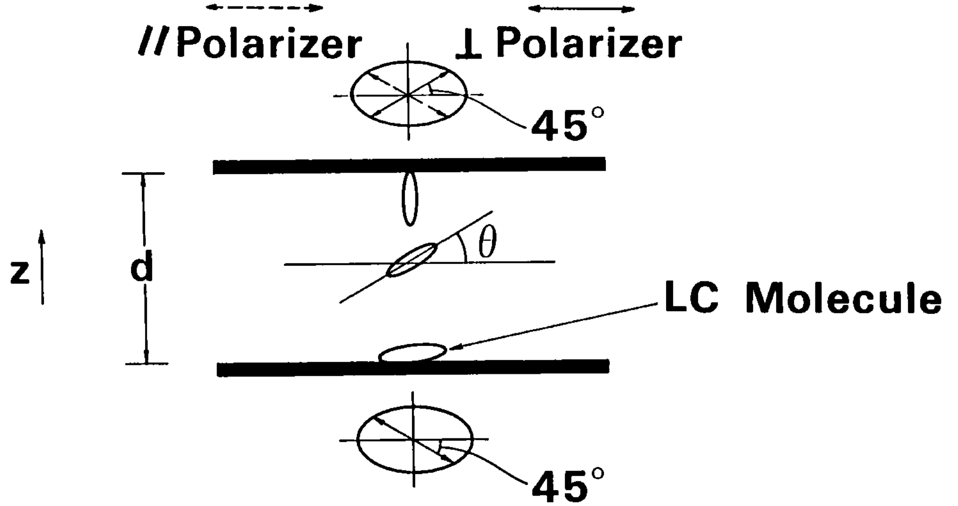

FIGURE 1 Conception of a HAN ECB effect LCD.

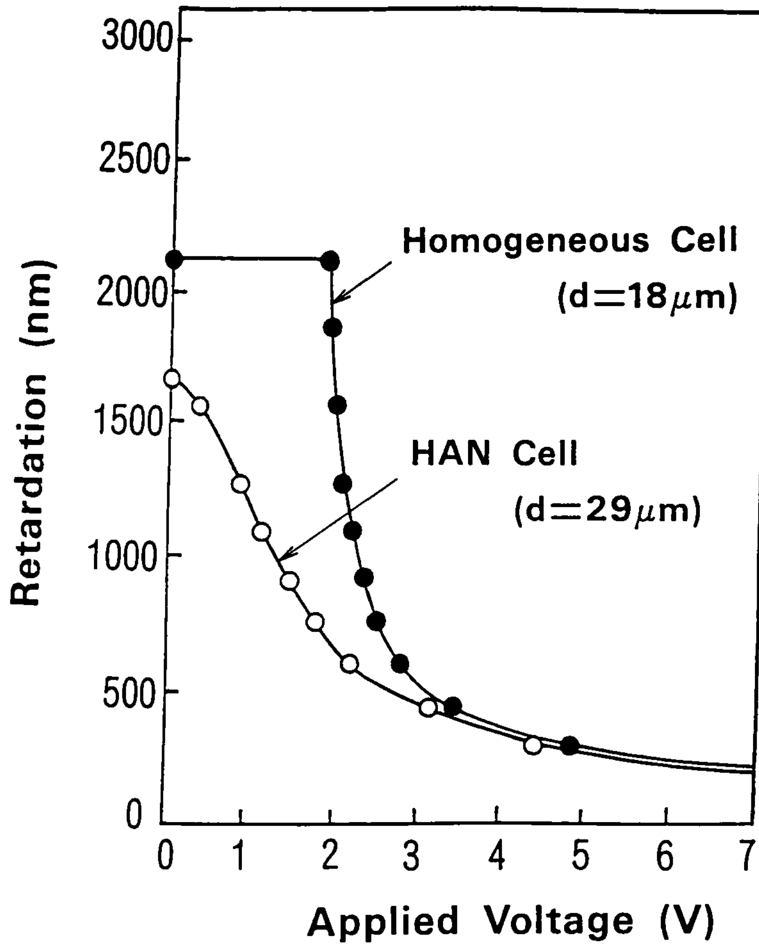

FIGURE 2 Retardation change in a HAN cell and a homogeneous cell.

retardation is shown in case of a homogeneous cell where both substrates have parallel alignment LC layers. A HAN LCD has no threshold voltage and its voltage dependence of retardation is dull compared with a homogeneous cell. This shows that a HAN LCD has such preferable features, from a viewpoint of a TFT-addressed LCD application, as good controllability of display color by applied voltage, *i.e.*, good color separation, and low voltage operation.

3. CONSTRUCTION OF A TFT-ADDRESSED HAN LCD

The construction of a TFT array used is shown in Figure 3. It consists of 240 (horizontal) × 220 (vertical) picture elements, 240 drain lines and 220 gate lines. Respective picture element pitches in horizontal and vertical directions are 190 μm and 155 μm and its active area is 34.1 × 45.6 mm^2. The opening is about 60%.

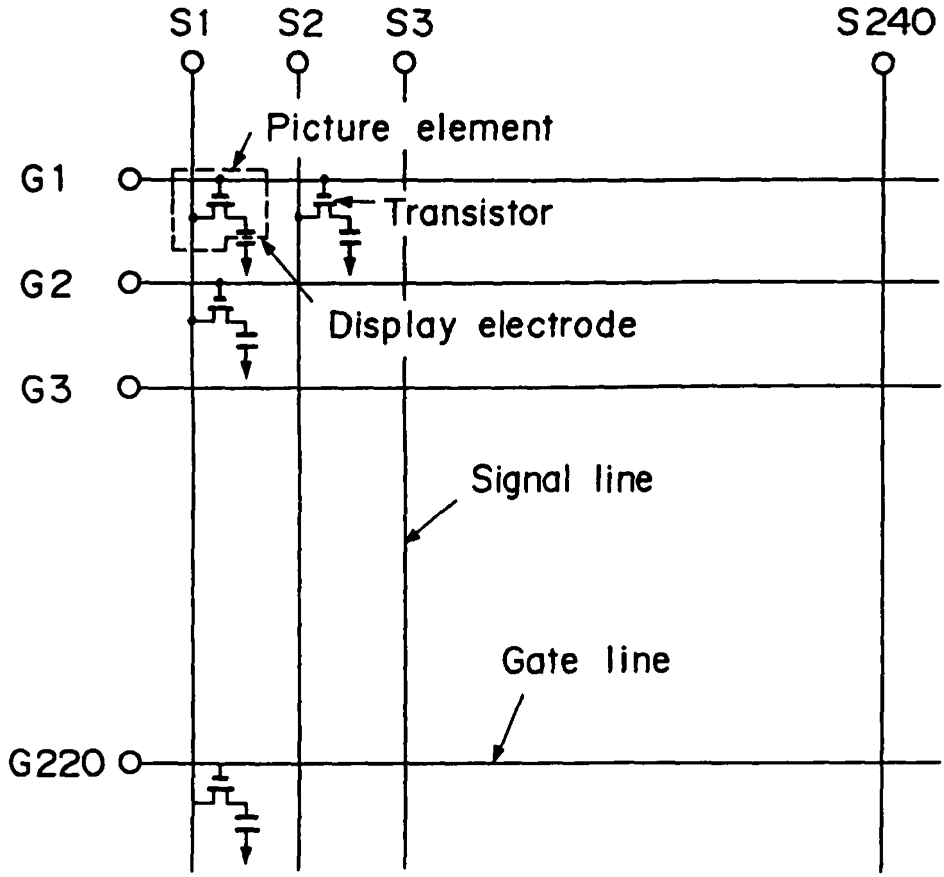

FIGURE 3 TFT array configuration.

The TFT array is fabricated on a glass substrate. Each line is connected to a driving circuit with a conductive elastmer. Each element comprises a TFT and a transparent display electrode. A light-shield metal covers a whole TFT region. The TFT has an inverse-staggered structure and its semiconductor layer is made of a–Si:H. Ion/Ioff is more than 10^6.

A cross sectional view of TFT-HAN LCD is shown in Figure 4. The TFT array substrate is treated with a perpendicular LC aligning agent of a perfluorononanoatochromium complex (PFNCC).[7] The counter glass substrate with a transparent electrode is covered with a polyimide layer rubbed in one direction for parallel LC alignment. The combination of such two kinds of aligning treatments achieves a stable hybrid alignment. A liquid crystal material is filled in the cell comprising the above-mentioned substrates. A polarizer is applied on the counter glass substrate. Its axis makes an angle of 45 degrees with the rubbing direction, while an analyzer is placed on the TFT array substrate. Its axis is arranged perpendicularly or parallel to the polarizer axis, depending on desired display colors.

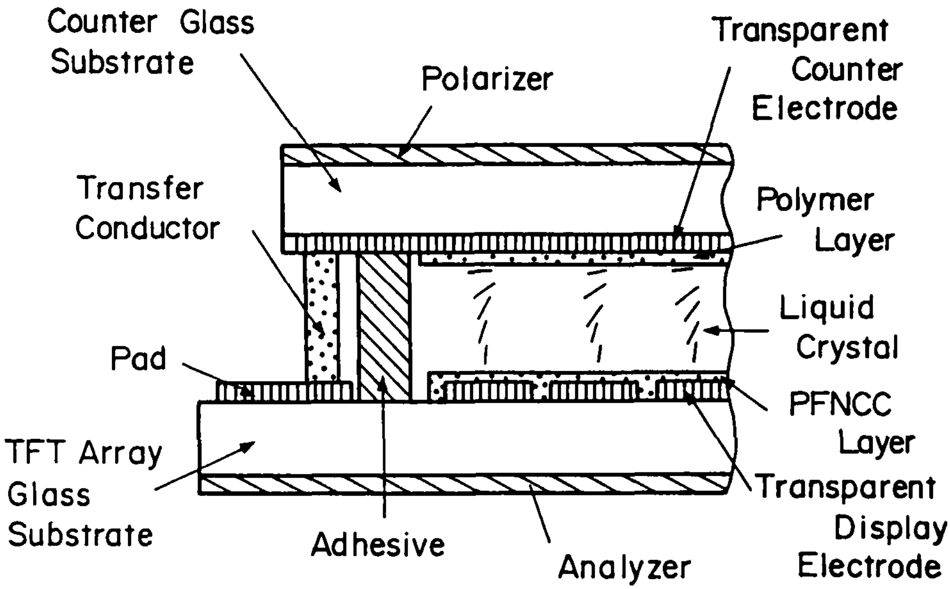

FIGURE 4 TFT-HAN LCD panel construction.

4. DRIVING WAVEFORM

A conceptional diagram of TFT-HAN LCD is shown in Figure 5. When an address voltage Vg is applied to the gate of a TFT (selected term), a drain voltage Vd is transfered to the display electrode. When a ground potential is applied to the gate (non-selected term), the display electrode is insulated from the drain. The display electrode voltage is held until the next address voltages is applied to the gate, if the electrical resistivity of LC layer is sufficiently high. The LC is activated by the voltage between the display electrode and counter electrode.

The driving waveforms of gate lines and drain lines are shown in Figure 6. Each gate line is selected every 16.4 ms. The address voltage Vg is 20 V for selected term and 0 V for non-selected term. The drain voltage Vd is 8 ± Vsig volts; the signal voltage Vsig can take eight steps in the range from 0 to 7 V, corresponding to a display color. The polarity of the voltage applied to LC layer is reversed every 16.4 ms.

5. ELECTRO-OPTICAL CHARACTERISTICS

Conventional static-drive HAN LCDs, filled with two kinds of LC materials and having two kinds of cell thicknesses of 18 and 29 μm, were prepared. One of LC materials is a phenylcyclohexane (PCH) LC mixture, which has a small birefringence $\Delta n = 0.12$ and a high electrical resistivity $\rho = \sim 10^{12}$ Ωcm. The other is a biphenyl (BP) LC mixture, which has a large $\Delta n = 0.24$ and a low resistivity

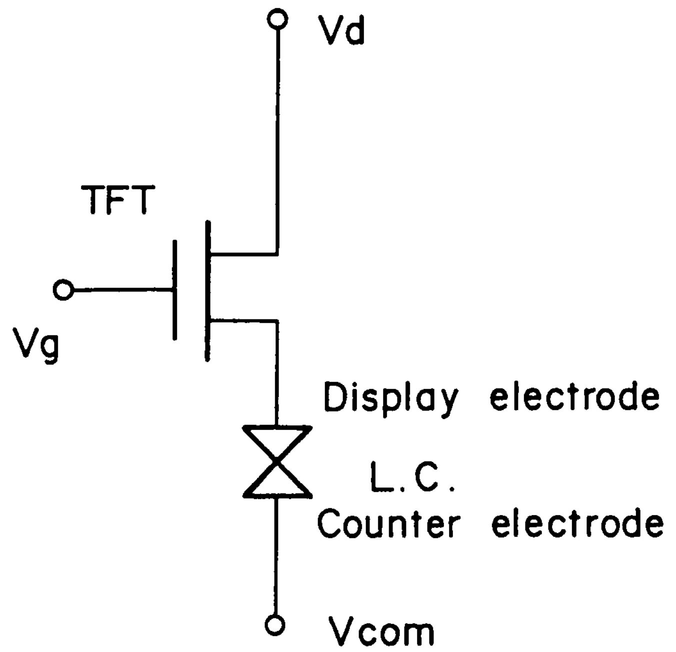

FIGURE 5 Conceptional diagram for TFT-HAN LCD.

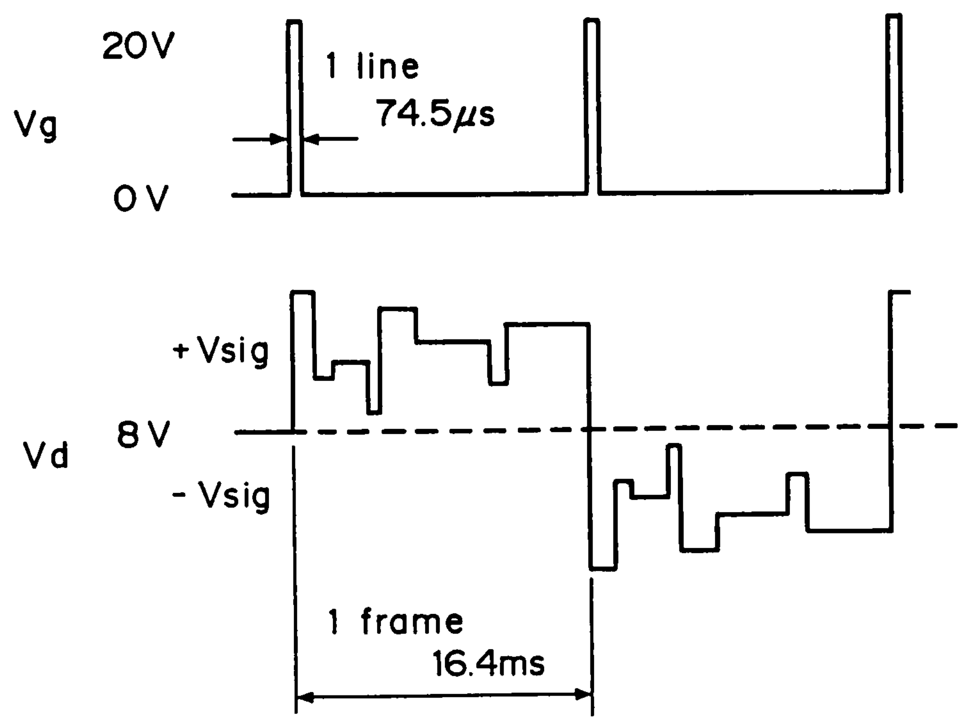

FIGURE 6 Driving waveform for a TFT-HAN LCD.

ρ = ~10^{10} Ωcm. The cell thicknesses were controlled within ±0.2 μm so that uniform display color is generated in a whole display area.

The voltage dependence of optical retardation in four kinds of the conventional HAN LCDs are shown in Figure 7. They are statically driven with a 32 Hz ac square wave voltage. Among four HAN LCDs, one with the combination of a PCH mixture and 18 μm cell thickness does not seem to be acceptable, because its retardation is too small to generate various display colors. On the other hand, in case of the HAN LCD containing a BP mixture, especially with the 29 μm cell thickness, the optical retardation is sufficiently large and various colors are displayed depending on the applied voltage. This may be true for the other HAN LCDs except the above-mentioned PCH-18 μm LCD.

Based on the above-mentioned results, three kinds of TFT-HAN LCDs were fabricated, using the same LC materials and cell thicknesses, excluding the combination of a PCH mixture and the 18 μm cell thickness. Figure 8 shows the optical

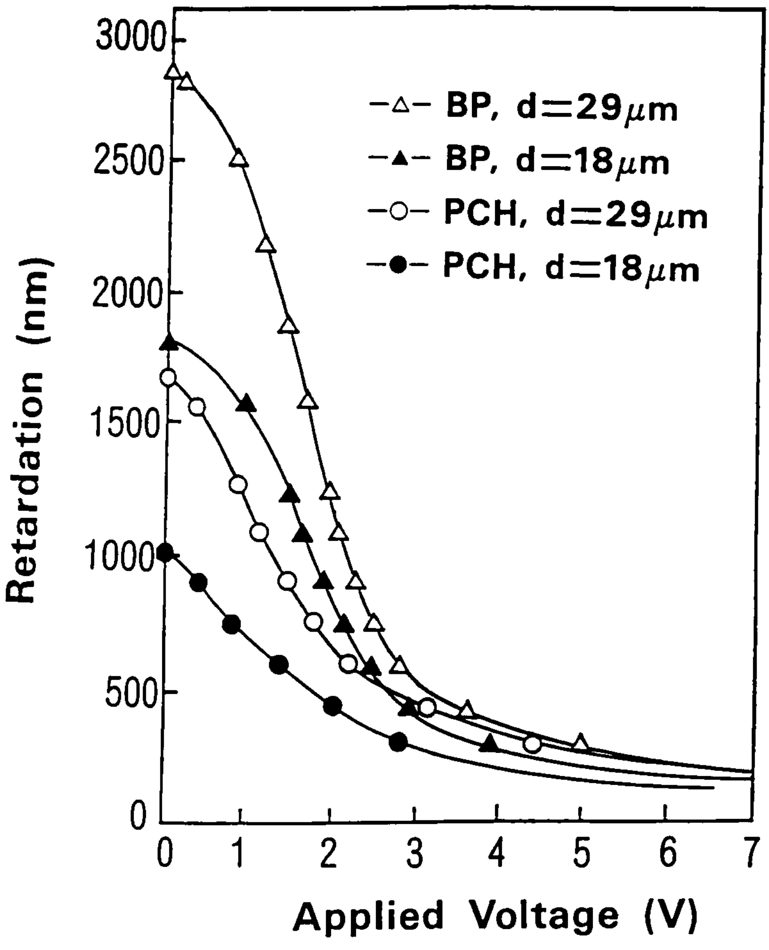

FIGURE 7 Voltage dependence of retardation of conventional HAN cells driven by static drive method.

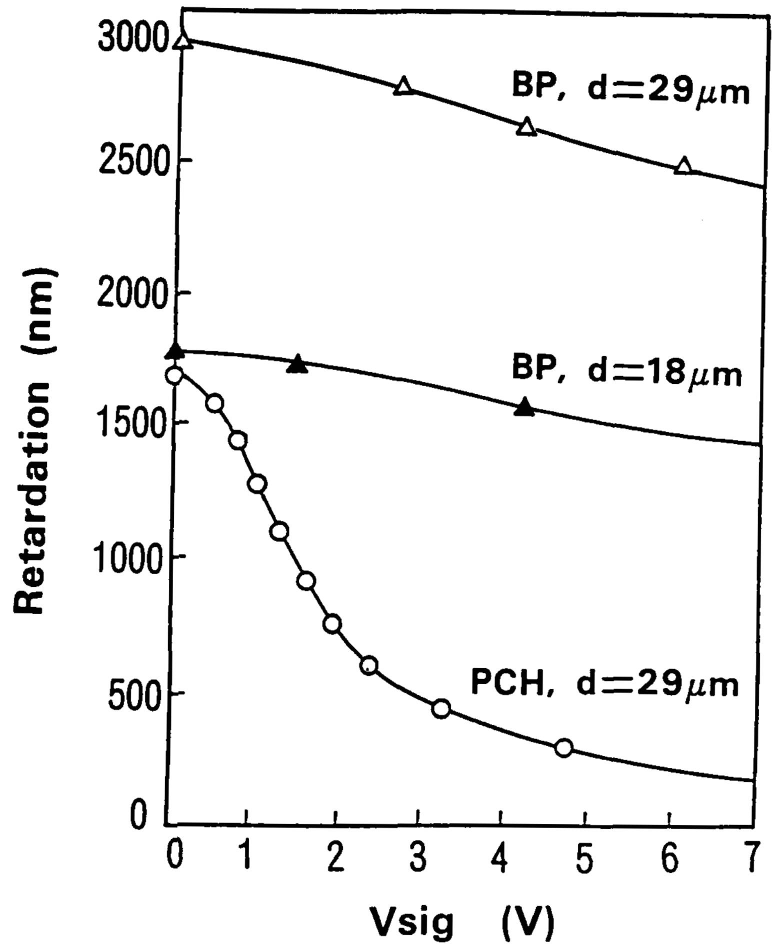

FIGURE 8 Voltage dependence of retardation of TFT-HAN LCD.

retardation versus signal voltage Vsig relation in the TFT-HAN LCD. In case of a PCH mixture, the retardation change with Vsig in the TFT-HAN LCD almost agrees with that in the corresponding conventional HAN LCD. This suggests that the voltage across the LC layer in the TFT-HAN LCD is almost held during a frame time.

In case of a BP mixture with the cell thicknesses d = 18 and 29 μm, the change of the retardation with Vsig is considerably small compared with the conventional HAN LCD. The effective voltage across the LC layer in the TFT-HAN LCD is estimated only about 15% of Vsig, by comparing Figures 7 and 8. The voltage across the LC layer is considered to decrease during the frame time, because of the low electrical resistivity of a BP mixture. So, the high resistivity of a LC material is prerequisite to a TFT-addressed LCD.

The cell thickness has to be chosen considering Δn value of a LC material so that the optical retardation becomes sufficiently large in order to generate various display color.

The above-described results show that the combination of a PCH mixture and the 29 μm cell thickness is the most suitable for the TFT-HAN LCD application.

6. DISPLAY PERFORMANCE

The display performance of the TFT-HAN LCD with a PCH mixture and the cell thickness of 29 μm is described below.

6.1 Display color

Display color change of the projected TFT-HAN display is shown in Figure 9. A halogen lamp is used as a light source and crossed polarizers are used. Various

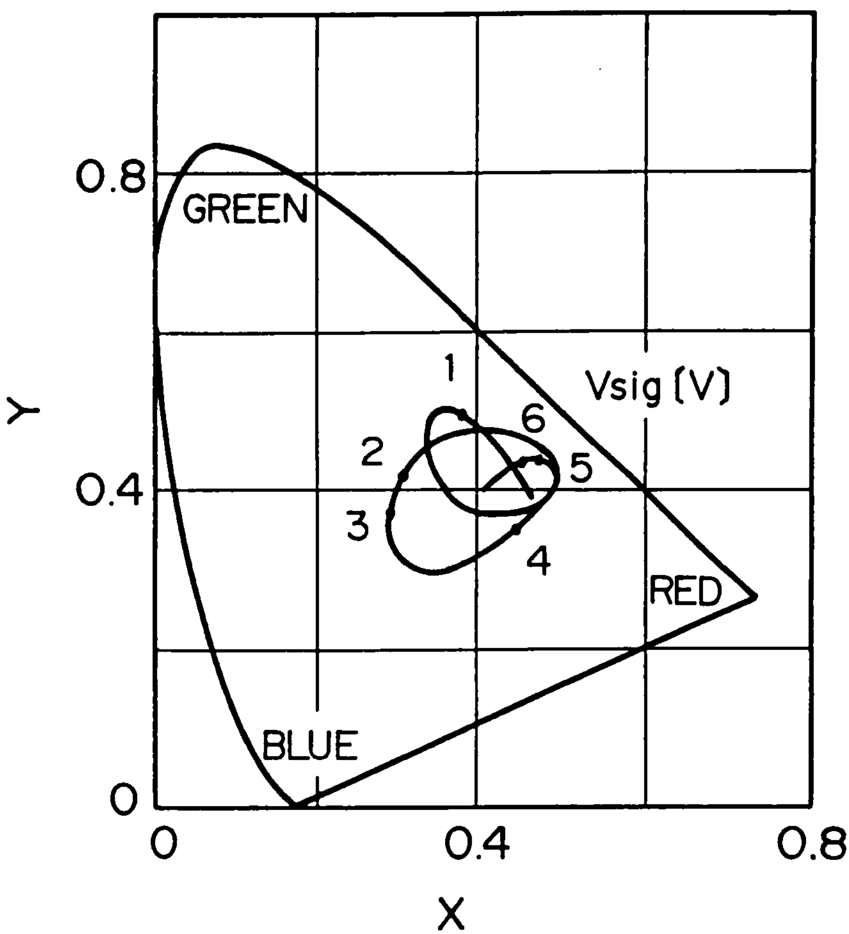

FIGURE 9 Voltage dependence of transmission color in a TFT-HAN LCD on the CIE chromaticity diagram.

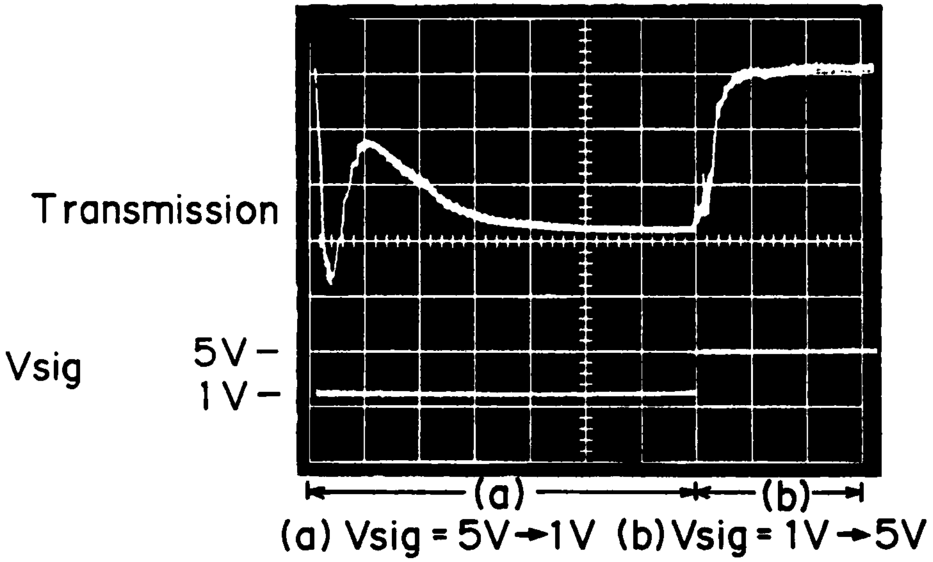

FIGURE 10 Transient behavior in a TFT-HAN LCD. (100 ms/div.)

display colors, such as red, orange, yellow, green, blue, purple, brown, white, etc. are generated, depending on the value of Vsig. The colors with parallel polarizers are complementary to those with crossed polarizers. The color purity is not excellent, but it is sufficiently acceptable for use in multicolor display.

6.2 Transient behavior

The transient behavior of the light transmission through the TFT-HAN LCD is shown in Figure 10. The portion (a) corresponds to the Vsig change from 5 to 1 V, while the portion (b) corresponds to the Vsig change from 1 to 5 V. The response time is defined as the time required for the transmission change of 90%, when Vsig changes from an initial voltage V1 to a switched voltage V2. Although the ambient temperature is about 25°C, the panel temperature is increased to about 40°C by the radiation from the halogen light source. The response time is about 400 ms with the Vsig change from 5 to 1 V, and its about 70 ms with the Vsig change from 1 to 5 V.

The voltage dependence of response time is given in Figure 11. The response time decreases with increasing V1 and V2. The signal voltage range is to be chosen depending on the desired colors and the desired response time. Another way to decrease the response time is to decrease the cell thickness as well as the viscosity of a LC material.

6.3 Light transmission

The light transmission of a TFT-HAN LCD including polarizers is about 20% and this value is nearly 5 times as large as that of a TFT color LCD with an RGB color filter. Therefore, this multicolor LCD can realize a bright display, even when it is

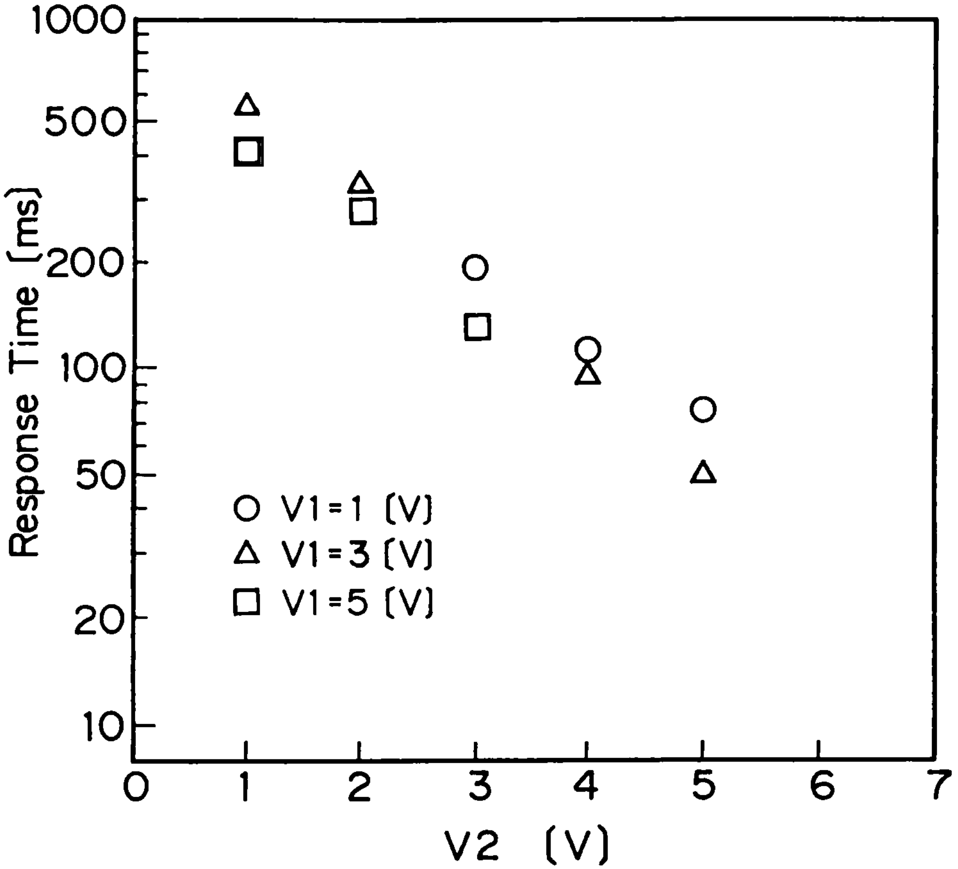

FIGURE 11 Voltage dependence of response time in a TFT-HAN LCD.

used for a large-area projection display. This multicolor LCD also achieves a high resolution display with 52800 picture elements because each pixel corresponds to each color pixel, *i.e.*, each pixel itself can generate various colors.

Figure 12 demonstrates a bright and high resolution multicolor large-area projection display by the developed TFT-HAN LCD.

7. SUMMARY

A liquid crystal multicolor projection display using a TFT-addressed HAN cell without a color filter has been developed. Compared with a TFT color LCD with an RGB color filter, it has such practically favorable advantages as five times brighter screen, three times higher resolution and no degradation of color. The TFT-HAN multicolor LCD is suitable for graphic and character display, since it has no gray scale capability.

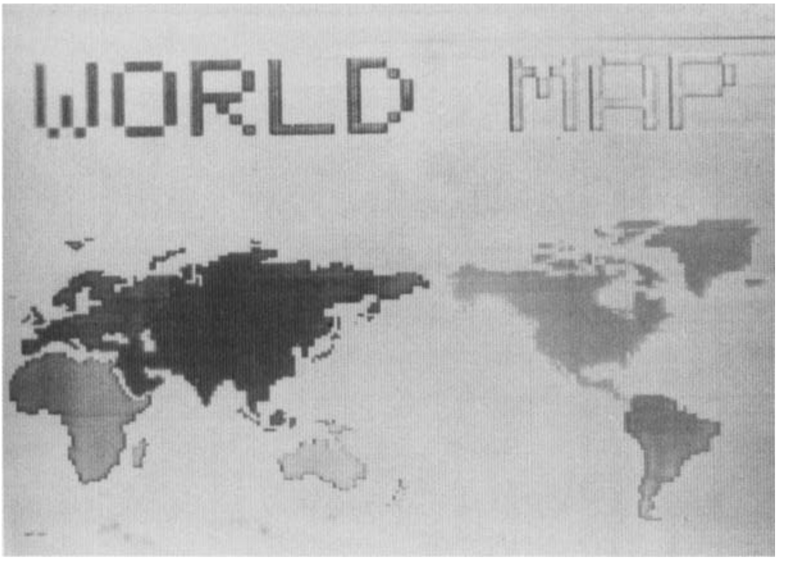

FIGURE 12 An example of multicolor graphic display projected on a screen.

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