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LCD & RELATED MATERIAL

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OPTOELECTRONICS--
LCD & RELATED MATERIAL

906C0054 Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 1-87

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Optoelectronics: Liquid Crystal Displays, Related Material: Introduction

906C0054A Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 1-6

[Article by Noriyuki Ibuki, Electrical Engineering Faculty, Setsunan University]

[Text] 1. Introduction

The role played by displays is becoming more and more important in the era of information processing systems. A display is a device that conveys information to us. More than 80 percent of all information enters into our minds through our eyes. Therefore, it can also be said that the display is a device for ensuring the cognition of various kinds of information with the eyes.

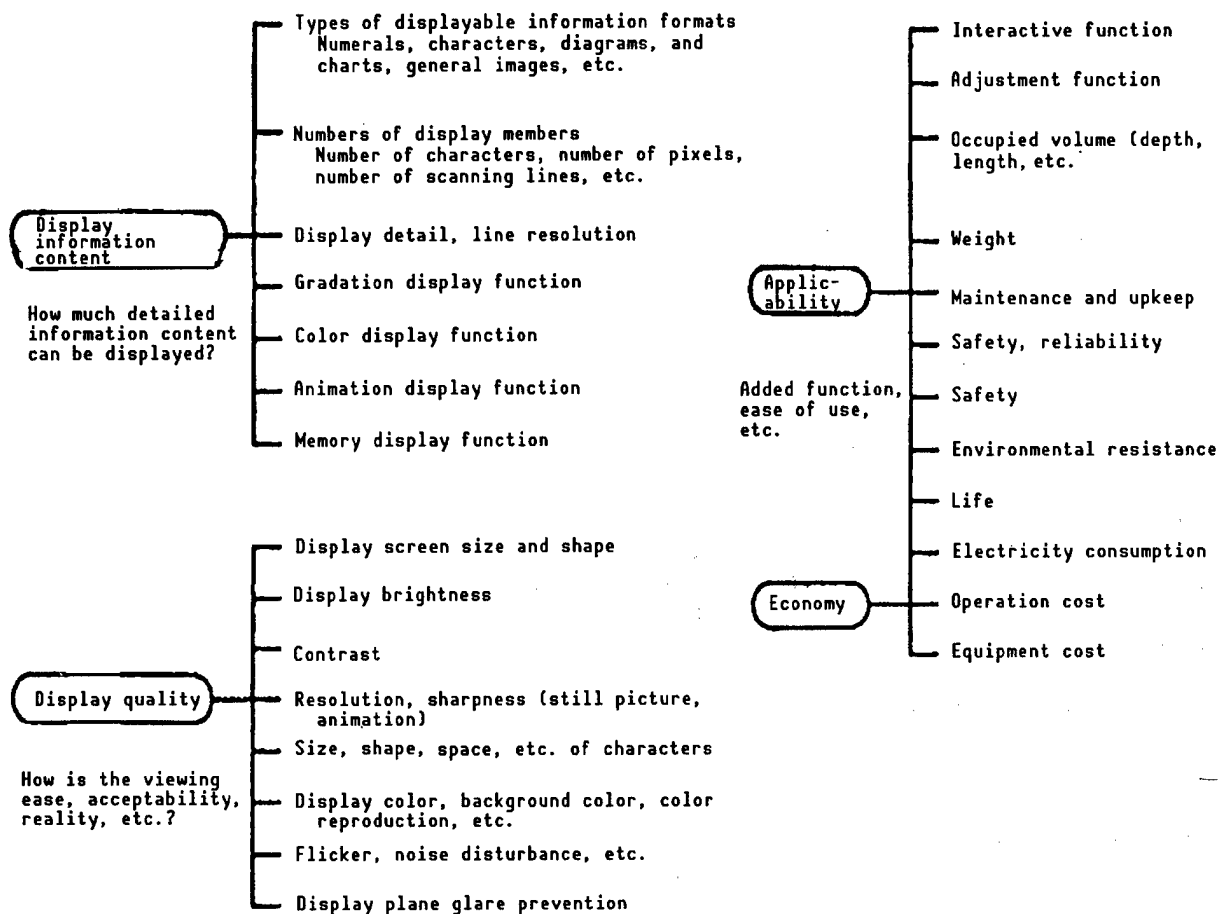
The performance of displays, including the television, has improved remarkably in compliance with the needs of the times, new devices have been introduced for office automation (OA), personnel, factory automation (FA), transport facility, and home automation uses, and display functions have increasingly grown. Interactive functions have also improved in response to the improvement demand required for these uses. As a result, various flat panel displays have been developed and employed widely, and superb large-sized displays have also been manufactured.

LCDs [liquid crystal displays] have been used widely under these conditions due to the great feature of low electricity consumption, and the prominent use in multiple aspects is increasing as performances improve. Here, we wish to make a survey of what is demanded of current displays and compare it with the LCD trend.

2. Functions and Performances Demanded of Displays

First, I would like to review the basic functions and performances demanded of displays. The basis of a display is to display the desired information which we desire as they are. It is desired that letters, graphic forms, and images be produced accurately, beautifully, and sometimes promptly and prominently. In addition, conditions such as being a device easy to use as a whole and having long life are also demanded.

Table 1. Basic Functions and Performances Necessary for Display System



When taking a look from a different angle, it will come down to the applicability of the information displayed, the quality of the displays, and the facility of use, as shown in Table 1. The types and numbers of displayed symbols, half tones, color tones, etc., are important for information volume; the effects of symbol size and resolution, contrast and luminous intensity, accuracy degree and strain, stability and noise, etc., are significant for the display quality, and the size and weight, electricity consumption, operability and repairability, etc., are the main factors in ease of use, and it can be said that the storing properties and interactive functions, etc., have come to be resolved recently.

To what extent these functions and performances will be demanded and which of these will be emphasized will differ according to the application of the respective displays, and this will be mentioned in the following chapter.

3. Various Displays and Their Applications

I would like to discuss the kinds of displays that are currently being used from various angles.

First of all, they range from large sizes for multiple uses to small sizes for personal use, and from one-dimensional displays to three-dimensional displays, like the hologram. Moreover, there are the light-emitting types like CRTs and the reflection types like ECDs, and they can be classified by the display speed, half tone, color, etc. In addition, classifications by use, such as for pleasure, communications, control, information processing, and education, can also be made.

Characteristic functions demanded of displays when observation conditions have been added to their applications are shown in Table 2. Low electricity consumption is mainly demanded for portable equipment, viewing ease is mainly demanded for those which will be observed continuously for a long period (OA equipment, etc.), natural animation is mainly demanded for TVs, etc., visibility and environmental resistance are mainly demanded for those vehicles loaded and used outdoors, and displays satisfying these respective demands are used.

4. Comparison of Various Displays

In response to demands from the various angles mentioned above, different display devices have been developed and are used. Table 3 compares the general performances of these display devices. The respective applications are determined according to these general performances. The display device generally offering high image quality and low cost is the CRT and, therefore, it has been widely used. However, a large capacity and weight are focused on, and they become problems when realizing a large picture plane. In contrast to this, the LCD features low voltage operation in which driving is facilitated by an ordinary LSI and electricity consumption is quite low and, therefore, it is practical for use in portable equipment. However, the image quality is inferior, and the improvement of this represents a significant topic. These conditions are shown together with those of other devices in Table 4.

However, the weight evaluating these performances will differ when it is limited to a certain application. Table 5 compares various devices when the OA equipment display is the focus.

Table 2. Main Applications of Display and Comparison of Respective Monitoring Conditions

Application	Monitoring distance	Monitoring attitude	Functions demanded characteristically
Compact, few numeral display indicators, such as watches, electronic calculators, measurers, etc.	30~50 cm	Concentrate and read	Reading ease Low electricity consumption property important in many cases
For office work, mainly handling characters and numerals, such as word processors, etc.	40~70 cm	Observe closely with almost same posture for a long time	Easy-to-read with not much fatigue
For high-degree diagrams and image processing of CAD and medical use			High precision position assignment, multicolor display, interactive function
For home color TVs	Standard system 6~8 H HDTV 3~4 H 1~3 m	Monitor casually, occasionally extended over time	Wide color reproduction Natural gradation Natural image display
For automobile dashboards, etc.	Around 70 cm	Grasp important information by brief glance, act promptly, precisely according to information	Visibility Environmental resistance (Temperature range especially wide)
Public display of data and messages (traffic slogans, etc.)	5~100 m		Visibility Environmental resistance

Table 3. Comparison of Various Displays

Item	CRT	VFD	PDP	EL	LED	LCD
Display mode	Emission	Emission	Emission	Emission	Emission	Light receptiveness
Operating voltage (V)	10~30kv	10~40	120~300	200	2	1.5~15
Response speed (μ s)	1	10	1~20	1~10	10	50~500ns
Memory	Nil	Nil	Possible	Possible	Nil	Possible
Display size	Small~large	Small~medium	Medium~large	Medium~large	Small~large	Small~large
Display capacity	Large	Small~medium	Large	Medium~large	Small~large	Small~large
Size	Large	Thin type	Thin type	Thin type	Small	Thin type
Luminescent color	ANY	Green (red, blue)	Orange (3 colors)	Yellow (3 colors)	Red, yellow, green	White/black (3 colors)
Display grade	o	o	•	•	o	o
Visual angle	o	o	o	o	o	Δ ~o
Electricity consumption	Δ	o	o	o	Δ	•
Life (Hr)	10^4	10^5	10^5	10^4	10^5	5×10^4
Main applications	Public welfare OA	Small-sized equipment OA Vehicle loaded equipment	OA FA	OA FA	Small-sized equipment For outdoors use Vehicle loaded equipment	Small-sized equipment OA Vehicle loaded equipment

Table 4. Comparison of Various Displays

	Main advantages	Main topics	Main themes
CRT	High image quality, low cost	Large sizing, high resolution realization	Flattening, lightweight
VFD	Low voltage operation, high luminous intensity	High resolution realization	Large sizing
PDP	Large sizing possible	Large capacity realization	Cost down, low operating voltage realization
EL	Easy-to-see	Multicoloring	Multicoloring, low operation voltage realization, efficiency improvement
LED	Low voltage operation, long life	Large sizing	Efficiency improvement of blue color
LCD	Low voltage operation, low electricity consumption	Backlight, high image quality realization	High response realization, image quality, backlight

Table 5. Comparison of Various Displays Intended for Office Automation (OA) Equipment

Item	CRT	VFD	PDP	EL	LCD
Large area realization	●	Δ	●	Δ	○
High resolution realization	○	○	○	○	○
Full coloring	●	○	○	Δ	○
Viewing ease	○	○	○	○	Δ→○
Drive voltage	x	○	Δ	Δ	●
Electricity consumption	Δ	Δ	Δ	Δ	○
Weight	x	Δ	Δ	○	○
Thickness	x	○	○	●	○
Cost	●	○	Δ	Δ	○

5. Demands on Various Devices

Here, I wish to again summarize the demands made on various devices in recent years. First of all, there are the high information display capacity, LSI drive, energy-saving, wide temperature range, flattening, consumption resistance, etc., on performances. Flattening is particularly demanded when realizing a large picture plane and using many displays, and the enlargement of the interactive capacity and its ease of use are strongly demanded when activating various information creation activities. Next, satisfaction is also an important topic from the using aspect. A good design and ease of operation are desirable, to say nothing of ease on the eyes. As for the software developed in recent years, that in which displays such as fragmentation, extension, superposition, etc., sufficiently satisfying demands can be freely made and satisfiable displays are available and are considered good. In addition, the fact that it is compatible with peripheral equipment is also a great factor.

Demands on large picture plane displays, one of the recent topics, are listed in Table 6. It goes without saying that electricity consumption as a whole should be held down.

Table 6. Requisites for Large-Screen Displays

A) Size			
Observers	200 inches	200 people	($\pm 45^\circ$, 3-18 H)
Distances			
Decipherable maximum distance	350-600 H		
Color mixture minimum distance	0.06° (Between pixels)		
Presence (ambience)	30-50°	(20-60°)	
B) Brightness			
	10:1-20:1		
Within bright room	400~1,500 cd/m ²		
Outdoors	3,000 cd/m ²		
C) Visibility angle			
	60°		
D) Economy			
High resolution	10 ⁴ dot/m ²		
Maintenance			

6. Trends of Various Display Devices

The improvement of various devices in response to the demands mentioned above is continuing. First, high detailing and large picture plane realization have been promoted on the CRT, and the fluorescent substance and electron gun and mask have become much better. Moreover, the development of various flat CRTs is being promoted for decreasing the weight. However, it appears that 50 inches is the limit for the direct-vision type, and the performance of the projection-type CRT has also been improved. On the other hand, those for OA are being pressed by the flat display.

Next, various efforts are being promoted toward increasing the size of the VFD from the structural aspect, etc. There are also new applications, such as vehicle loaded head wrap display, etc., for obtaining a high luminous intensity.

Since large area realization is comparatively easy in PDPs [plasma display panels], low pricing has been promoted together with the reduction of driving voltage and power and improvement of structure, and PDP has advanced into OA equipment. However, the coloring is delayed, and this delay represents a future topic.

Due to the advancements made in high luminous intensity and working life, LCDs have been used for outdoor displays and communications signals. The development of those of blue color and high efficiency is continuing.

In comparison with the various types of devices mentioned above, the large sizing and high image quality realization of LCDs are energetically being promoted. Together with the promotion of the mass production of LCDs using TFT with full color compact elements, those of 10-14 inches have been prepared in multicolors as well. Simple matrixes preventing coloring by means of various methods when using the STN liquid crystal have appeared. They are about 10 inches, have been prepared for multicolor and full color, the image quality has been improved to a 16 gradation, and low cost is being promoted through the preparation of a phase difference film. Therefore, although the applications are also being extended, large area realization and yield improvement for the TFT-type are aimed at as future topics and homogeneity realization and coloring improvement are demanded for simple matrixes. Moreover, the desire to brighten it by providing a backlight, as well as making it thin and of low cost, is strong while, on the other hand, efforts toward putting the ferroelectric liquid crystal to practical use are also awaited. In addition, attention is being paid to the development of the projection TV as a promising application.

Next, the progress of the application of the large area LSI technology and digital circuit is conspicuous from the driving circuit aspect.

Lastly, when observed from the application aspect, HDTV is demanded in TVs, flattening is demanded for OA equipment, information terminalization is demanded for OA and traffic equipment, and various approaches are being promoted in these directions.

7. Conclusion

The recent trends of displays, including LCDs, has been discussed above. The future market estimate is shown in Table 7, and it is believed that the demand for LCDs will increase more and more in the future together with performance improvement. In response to this, it is expected that many future developments will be announced by the Society.

Table 7. Output and Market Estimate of Main Display Devices
(Unit: ¥100 million)

	1986*	1987*	1988*	1989	1990
CRT	4468	4573	5170	5400	5900
For TV use	3070	2981	3325	3600	3800
For industrial use	1398	1424	1624	1600	1600
VFD	564	620	735	870	1000
PDP	150	200	260	340	400
LED	964	965	1020	1100	1200
LCD	634	857	1019	1400	1800

*MITI Mechanical Statistics (excluding PDP)

Table 8. Transition of Number of Theses at the Recent SID Related Society

	1986		1987		1988		1989	
	May U.S.	Sep Japan	May U.S.	Sep Europe	May U.S.	Oct U.S.	May U.S.	Oct Japan
CRT	15	17	18	9	9	7	10	14
VFD	1	4	1	0	1	1	0	1
PDP	6	7	4	4	6	3	4	25
EL	12	17	12	8	12	4	10	13
LED	0	1	0	0	0	0	0	1
LCD	12	57	13	22	5	1	6	61
Active matrix	7	13	9	17	18	11	9	16
Human factor	12	14	13	3	14	0	14	6

Recent Progress in Simple-Matrix LCDs

906C0054B Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 7-17

[Article by Hitoshi Hato, Electron Devices Engineering Laboratory, Toshiba Corp.]

[Text] 1. Introduction

The characteristics of liquid crystal displays (LCDs) are that they are thin, lightweight, and have low voltage drives and low electricity consumption. They are also widely used for TVs and vehicle loaded displays in addition to displays for OA equipment, such as personal computers and word processors, and expectations for their development and dissemination are not limited to industrial circles, but have also been linked to social needs.

The LCD driving system can be largely classified into the active matrix system that provides a switching element for each pixel, and the simple matrix system that does not use a switching element. Since the simple matrix drive LCD does not use a switching element, it is generally more advantageous than the active matrix system in such aspects as productivity, cost, reliability, and large picture plane realization. The simple matrix drive LCDs are mainly adopted for the large picture plane display of information transfer equipment, including OA equipment, and are now indispensable as displays for the word processors and personal computers that have become familiar to us. Especially the super-twist (ST)-type LCD has made remarkable progress in recent years, having been installed in word processors and personal computers, and has greatly contributed to the popularization of these equipment items.

In addition, the vertically aligned nematic (VAN) LCD¹⁻² of the simple matrix drive, which utilizes a cell in which the negative liquid crystal is vertically orientated by the inductive isomerism and conducts display by the double refraction effect, essentially offers achromatic color and has been especially reconsidered in recent years since it is suited for high multiplex drives.

In this article, explanations will be made of the simple matrix drive LCD, particularly focusing on the recent development trend involving retardation film (RF) system achromatic color ST-type LCDs³⁻⁴ and VAN-type LCDs.

2. Retardation Film (RF) and System Achromatic Color ST-Type LCD

2.1 Various Achromatic Color Techniques of ST-Type LCD

The twisted-nematic (TN)-type display system was the main current for the simple matrix drive LCD until several years ago, but since the display capacity of this system could not comply with the needs of realizing a large display capacity in the information and OA related equipment fields, a majority of large-sized dot matrix drive LCDs with duty ratios exceeding 1:100 is currently adopting the super-twist (ST)-type display system. When first being manufactured, the ST-type LCD could not avoid being colored yellow or blue, as seen from the common name given to it as the yellow mode LCD or blue mode LCD. However, these display colors were not desirable from a visual sense, and problems were involved, such as the coloring being difficult, etc. Various attempts have been made to make the background color achromatic to improve these points (Table 1).

Table 1. Performance and Characteristics of Various Achromatic Color ST-Type LCDs

	W-ST	LR-ST	GH-ST	D-ST	RF-ST
Display principle	Coloring is erased by color polarizing plate	(Low retardation) Δ and is made small	Black dye is used	Polarization is corrected by inverse helical cell	Polarization is corrected by retardation film (RF)
Display mode	Reflection	Reflection/semi-transmission	Transmission	Transmission/reflection	Transmission/reflection
Background color	White (Ash)	Blue	White	White	White
Lighting color	Blue	Black	Black	Black	Black
Contrast ratio	~5	~7	~15	~20	~20
Brightness	o	Δ	x	o	o
Responsibility	o	o	x	o	o
Thickness/weight	o	o	o	x	o
Coloring	x	x	Δ	o	o
Mass productivity	o	o	o	Δ	o

In the white (W)-ST, the yellow background has been made achromatic with the application of a purple deflector to the yellow mode ST-type LCD, and it has been put to practical use in the reflection-type OA equipment LCD.

The low retardation (LR)-ST^{6,7} conducts an achromatic color display by making the cell retardation $\Delta n d$ and of $0.6\sim 0.7\ \mu\text{m}$. It has been applied to LCDs for fish detectors, etc. The guest host (GH)-ST adds black dichromatic dye to the liquid crystal and produces a black-and-white display by the guest host effect. Since the transmittance is low, ST-type products to which this system has been applied are not common.

The driving cell and torsion directions are opposite in the double (D)-ST⁸ and, furthermore, with $\Delta n d$ being of a two-layer cell structure with an additional compensating cell, black-and-white display is conducted by compensating for the elliptical polarization generated at the driving cell by the compensating cell. It is possible for D-ST to conduct a real black-and-white display of paper white, with both the contrast ratio and brightness (transmittance) being good, and it is also suited for application to color displays and has been put to practical use as an LCD for transmission-type OA equipment. However, since D-ST uses two cells, there are problems in that it is inferior in mass productivity, as well as bringing increases in thickness and weight.

The retardation film (RF)-ST³⁻⁵ uses a phase difference film consisting of an organic polymer in place of the compensating cell in D-ST. The phase difference film has a thickness one-fifteenth and weight one-twentieth those of the liquid crystal cell and, since it will suffice to merely paste the phase difference film to the liquid crystal cell, it excels in mass productivity. As seen here, the RF-ST-type LCD has practically the same superior display performance as the D-ST and may be called the superior LCD that has solved the defects of the D-ST. Ever since the Toshiba Corp. successfully mass produced it for the first time in autumn 1988, developments on this retardation film (RF) system LCD have progressed in various companies. It is currently being made into products by several companies, and it is expected to represent the main current of LCDs in the future.

2.2 Composition and Display Principle of RF-ST Type LCD

Generally, the light transmitting oval polarization of the ST-type liquid crystal cell differs by wavelength, so a color appears in the display. For example, the polarization of the transmittance light of a blue mode display is shown in Figure 1. In contrast to all lights of any wavelength transmitting and displaying a white color when voltage is applied, only the blue light is transmitted when no voltage is applied and it becomes a blue display.

As shown in Figure 2, the retardation film system (RF)-ST-type LCD is of a composition in which the retardation film (RF) has been placed between the liquid crystal cell and polarizing plate. Generally, an organic polymer film of polycarbonate or vinyl alcohol is drawn, while one having optical anisotropy is used for the retardation film. By rationalizing the retardation value of the retardation film and configuration of the optical axis, the wavelength dependence of elliptical polarization in the ST-type LCD mentioned above can be compensated for and an achromatic color display becomes possible.

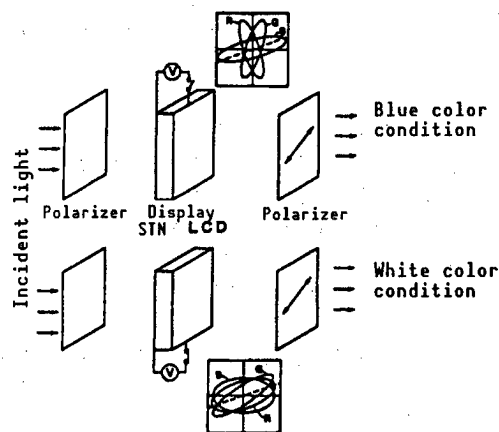


Figure 1. Display Principle of Colored ST-Type LCD

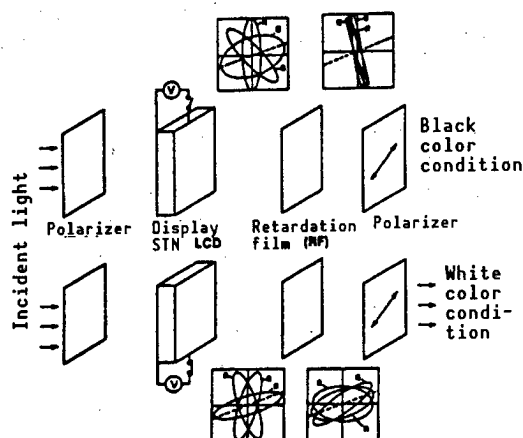


Figure 2. Display Principle of Retardation Film System
Black-and-White ST-Type LCD

In other words, as we see in Figure 2, if it is made so that light of all wavelengths will be transmitted when voltage is applied and, furthermore, when no voltage is applied, light of all wavelengths will become elliptically polarized approaching linear polarization, it becomes possible to have the so-called "normal black mode" and black-and-white display, i.e., a white display on a black background.

2.3 Optimization of RF-ST Type LCD Cell Composition

2.3.1 Simulation analysis of display performance

Since the number of cell parameters affecting the display performance of the RF-ST-type LCD is extremely great, the experimental analysis of display characteristics is difficult. Therefore, computer simulation analysis was conducted.

First, the elastic body theory was used, and the orientation distribution of the liquid crystal molecules in the ST-type LCD cell was obtained at the ON and OFF of a 1/200 duty drive. In this case, the torsion angle of the liquid crystal cell was assigned a 240° counterclockwise rotation.

Then, using these results, the various optical cell parameters were changed and the wavelength dependence of the electrooptical characteristics of RF-ST-type LCDs was calculated by the Berreman 4 x 4 matrix method. The C standard light source was used, the observation direction was the cell normal line orientation and studies were made by the transmission type. Moreover, the display chromaticity (a^* , b^*), saturation C^* ($= ((a^*)^2 + (b^*)^2)^{1/2}$) and lightness L^* were obtained. Evaluation parameters L^* and C^* are extremely important as parameters related to contrast ratio and achromatic chromaticity.

For example, the following procedures are effective when studying the cell conditions of high contrast and black-and-white display LCDs.⁴

- (1) Search for the cell condition in which L^* becomes small when OFF. (Black display)
- (2) Obtain the cell conditions when L^* is inversely large and C^* is small at OFF in (1) above. (White display)

The reason for turning our attention to lightness L^* here and not directly to saturation C^* is that human eyes depend very little on saturation C^* and are able to recognize it as black as long as lightness L^* is small to a certain degree (as long as the transmittance is small). The cell composition of the normally black LCD can be optimized by the procedures mentioned above. Moreover, it would be appropriate to replace the ON and OFF mentioned above for the normally white mode.

In addition, the calculated and experimental results were made to coincide well by introducing in advance the wavelength dependence of the liquid crystal material double refraction ratio and the wavelength dependence of the transmission of polarized plates and retardation film.

2.3.2 Arrangement and display performance of retardation film

The number of retardation films and the display performance characteristics of the RF-ST type LCD are shown in Table 2. When a single retardation film is used, a black-and-white display is possible, but the contrast ratio is small.^{3,4} Inversely, when many retardation films are used, the cell composition becomes complicated, which is not desirable from the aspects regarding lowering costs, film thickness and weight. Therefore, it can be concluded from these viewpoints that using two retardation films is optimal for the cell composition of the RF-ST-type LCD. In this case, it can be largely classified into two types by the structure of the two retardation films. In other words, there is the a type, in which two retardation films are inserted between the liquid crystal cell and one of the polarizing plates, and the b type, in which one retardation film is placed on each side of a liquid crystal cell and is held between a polarizing plate. The optimum cell composition obtained for each of these two types by the evaluation method mentioned above is shown in Table 3.

Table 2. Number of Retardation Films and Display Performance Characteristics of RF-ST-Type LCD

No. of retardation films	Achromatic color degree	Contrast ratio	Cost	Thickness/weight
One piece	Δ	x (~8)	o	o
Two pieces	o	o (~20)	o	o
More than three pieces	o	o (~25)	x	x

Table 3. Two Types of Compositions and Display Performances of Retardation Film Two-Piece System RF-ST-Type LCD

Cell composition	Optimized value by simulation		Display performances (measured values)	
	Δ nd (μ m)	RF retardation value (same value for both pieces) (nm)	Contrast ratio	Transmittance (%)
Type a (double-ply type)	0.68	365	20	21.6
Type b (sandwich type)	0.82	400	22	21.0

The 1/200 duty drive RF-ST-type LCD with 640 x 400 dot picture elements was actually trial manufactured based on these results. The results of measuring the contrast ratio (CR) and the transmittance at ON of these LCDs are shown in Table 3. The contrast ratio (CR) of the b type is slightly higher than that of the a type, and it is recognized that the transmittance is slightly less.

On the other hand, the visual angle characteristic of the contrast ratio (CR) is shown in Figure 3. It is known that the angle of visibility of the a type is wider than that of the b type.

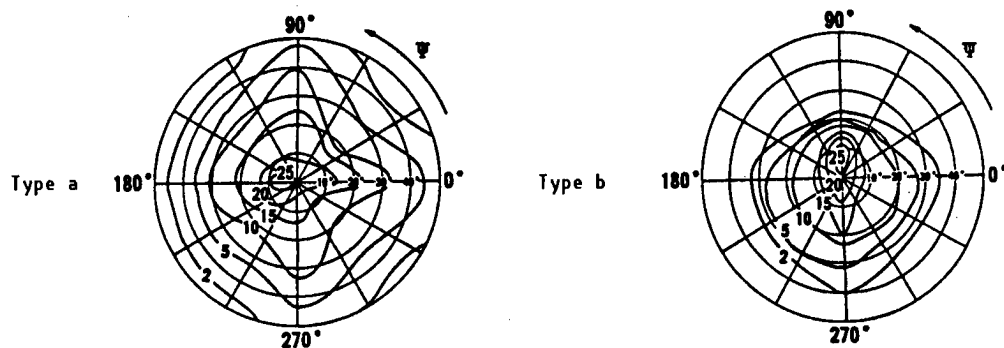


Figure 3. Visual Angle Dependence of Contrast of Two Types of Retardation Film Arrayed RF-ST Type LCDs

From the above study results, the cell composition of the a type, in which two retardation films have been inserted between the liquid crystal cell and one polarizing plate, was made the optimum from such viewpoints as the contrast ratio, transmittance, and angle of visibility, and the black-and-white display retardation plate system ST-type LCD with a high contrast and wide angle of visibility using this configuration was termed the M (monochrome)-ST-type LCD.

2.4 Cell Condition Dependence of M-ST-Type LCD Display Performance

The retardation (R) dependence of the contrast ratio (CR) and chroma (C°) in the M-ST type LCD is shown in Figure 4. The contrast ratio (CR) reaches its maximum value (CR_{max}) at $R_0 (=365 \text{ nm})$, and then reduces suddenly as R shifts from R_0 . The range of R in which more than $CR_{max}/2$ is available is $R_0 \pm 7 \text{ nm}$. On the other hand, chromas at both ON and OFF show a reducing trend in the neighborhood of R_0 as R increases. Therefore, the R range in which a high contrast and black-and-white display is available becomes $R_0 - 3 \text{ nm} - R_0 + 7 \text{ nm}$ and is asymmetric against R_0 .

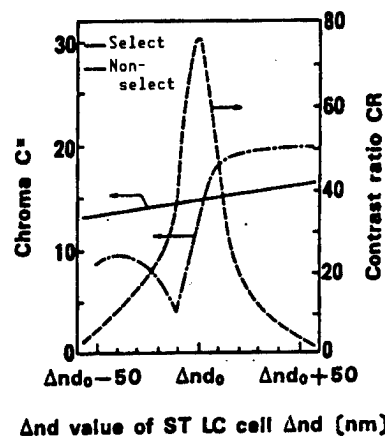
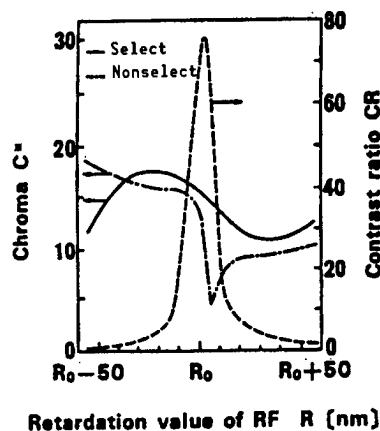


Figure 4. Retardation (R) Dependence of Contrast Ratio (CR) and Chroma (C°) in M-ST-Type LCD

Figure 5. Δnd Dependence of Contrast Ratio (CR) and Chroma (C°) in M-ST-Type LCD

The calculated results of the liquid crystal cell retardation $\Delta n d$ dependence of the contrast ratio (CR) and chroma (C°) when $R = R$ are shown in Figure 5.

CR reaches its maximum value ($CR_{\max}$) at $\Delta n d_0$ ($=680$ nm), and the range of $\Delta n d$ in which more than $CR_{\max}/2$ is available is $\Delta n d_0 \pm 10$ nm.

On the other hand, chromas at both ON and OFF show an increasing trend in the neighborhood of $\Delta n d_0$ as $\Delta n d$ increases. Therefore, the $\Delta n d$ range in which a high contrast and black-and-white display is available becomes $\Delta n d_0 - 10$ nm $\sim$ $\Delta n d_0 + 5$ nm, and is asymmetric against $\Delta n d_0$.

The cell conditions (R value of retardation film, $\Delta n d$ of liquid crystal cell, etc.) for obtaining a high contrast and black-and-white display in the M-ST-type LCD can be designed by following the above notes.

2.5 Color Display Retardation Film System ST-Type LCD

A multicolor display dot matrix LCD has been developed by combining the M-ST-type LCD mentioned above and the RGB color filter substrate.⁵ The specifications for this LCD are shown in Table 4. The display picture size is about A4, consists of 640 x RGB x 480 picture elements and is driven at a 1/240 duty ratio.

Table 4. Specifications and Display Performance of Retardation Film System Color ST-Type LCD

Panel size	263(H) x 223(V) mm ²
Display area	230(H) x 173(V) mm ²
Number of pixels	640 x RGB (H) x 480(V)
Color filter	RGB stripe
Drive duty	1/240 duty ratio
Contrast ratio	20:1
Angle of visibility	60° cone (CR > 4)

A gradation display is made and 16 colors are displayed. The contrast ratio from the LCD normal line direction is 20:1 and the angle of visibility with the contrast ratio exceeding 4 is a 60° cone. An example of the multicolor display retardation film system ST-type LCD developed is shown in Figure 6 [not reproduced].

2.6 Conclusion

As already mentioned, the retardation film system ST-type LCD not only excels in display performances such as contrast ratio, brightness (transmittance), etc., but is also superior in the aspects of thickness, weight, mass productivity, etc., and it can be said to be today's most advanced LCD.

The development and commercialization of the retardation film used for this LCD has just started, and the realization of a higher display grade RF-ST-type LCD can be expected in the future through improvement and optimization

(improvement of optical nonuniformity, improvement of durability and reliability, optimization of retardation wavelength dependence, and three-dimensional optical anisotropy).⁹

3. VAN-Type LCD

3.1 Driving Principle of VAN-Type LCD

When voltage is applied to a liquid crystal cell, the molecular array of the liquid crystal changes due to the dielectric anisotropy of the liquid crystal and, as a result, the birefringence rate in the cell changes. When a liquid crystal cell is placed between two polarizing plates, the change in this birefringence rate appears as the change of the light transmittance, and this is called the electrically controlled birefringence (ECB) effect.

The homeotropic orientated cell in which the liquid crystal director is perpendicular to the substrate is used in the VAN-type LCD and display is produced by the ECB effect. A monobasic chrome complex and long chain alkylsilane are used as the orientation film for inducing the vertical direction on the substrate, and a Nn liquid crystal with a negative dielectric anisotropy is injected in the cell. This composition is also called the DAP (deformation of vertical aligned phase) form.¹⁰

The relationship between the applied voltage and retardation δ is expressed approximately by the following equation in the VAN-type LCD.¹¹

$$\delta = \frac{2\Delta nd}{\lambda} \cdot \frac{1}{\kappa + 1 + |\Delta\epsilon|/\epsilon_r} \cdot \frac{V - V_0}{V_0} \quad (1)$$

Here,

$$V_0 = \pi [k_{33}/(\epsilon_0 |\Delta\epsilon|)]^{1/2} \quad (2)$$

$$\kappa = (k_{11} - k_{33})/k_{33} \quad (3)$$

However, when an orthogonal polarizing plate is placed in front and back of the VAN-type liquid crystal cell, the relationship between the retardation δ and transmission light Tr is expressed by the following equation.

$$Tr = A \sin^2(\delta/2) \quad (4)$$

When voltage is not applied, the liquid crystal molecules are vertically orientated to the substrate, the retardation δ is 0, and the transmission light $Tr = 0$ becomes dark. The retardation δ increases as the applied voltage is increased from the threshold voltage V_0 , and the transmission light changes correspondingly. In this case, the greater the Δnd and k_{33}/k_{11} and smaller the $|\Delta\epsilon|/\epsilon_r$, the more sharply transmission light changes against the applied voltage.

When the VAN-type LCD uses an orthogonal Nicol prism, it is capable of displaying a perfect black (white in case of a parallel Nicol prism) in the electric field voltage unapplied condition. It is essentially an achromatic display and is characterized by a high contrast.

3.2 Electrooptical Characteristics of VAN-Type LCD

3.2.1 Steepness γ and Visual Angle Dependence β

The change in the VAN-type LCD when changing the applied voltage-transmittance curve and visual angle ϕ generally becomes that shown in Figure 7. The steepness γ and visual angle dependence β are defined by the following equations from this drawing.

$$\gamma = \frac{V(\phi=0^\circ, Tr=50\%) - V(\phi=0^\circ, Tr=5\%)}{V(\phi=0^\circ, Tr=5\%)} \times 100\% \quad (5)$$

$$B = 2 \cdot \frac{V(\phi=0^\circ, Tr=5\%) - V(\phi=20^\circ, Tr=5\%)}{V(\phi=0^\circ, Tr=5\%) + V(\phi=20^\circ, Tr=5\%)} \times 100\% \quad (6)$$

The smaller the steepness γ , the higher is the possible multiplex drive, and the smaller the visual angle dependence, the wider the angle of visibility.

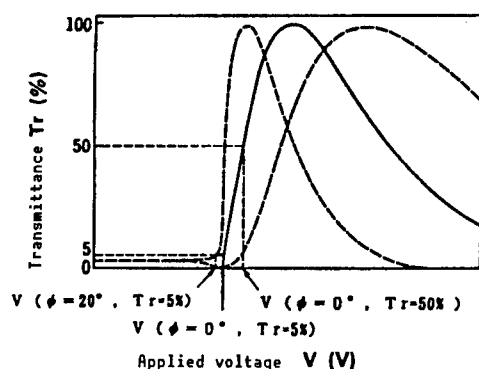


Figure 7. Tr-V Characteristic of VAN-Type LCD

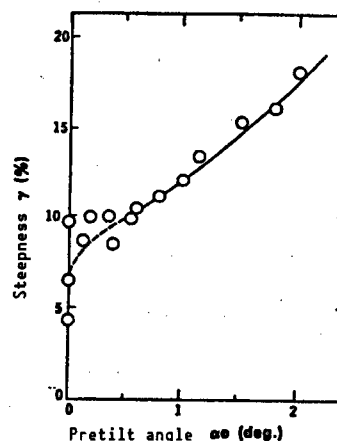


Figure 8. Relationship Between Pretilt Angle α_0 and Steepness γ

3.2.2 Pretilt angle α_0 and steepness γ

In the VAN-type LCD, it is necessary to tilt the liquid crystal molecules slightly from the substrate surface in the voltage unapplied condition to prevent the inclination of the liquid crystal molecules to one direction and the generation of the discrimination defect when voltage is applied.

The relationship between the pretilt angle α_0 and steepness γ in the VAN-type LCD is shown in Figure 8. The Nn liquid crystal of the ester system is used for the liquid crystal material, the cell thickness d is $7 \mu\text{m}$ and a monobasic chrome complex is used for the orientation film. The steepness γ becomes

smaller as the pretilt angle α_0 decreases, but the dispersion of steepness γ becomes great at $\alpha_0 < 0.5^\circ$. The pretilt angle α_0 of about 0.5° is sufficient for practical use.

3.2.3 Liquid crystal blend and steepness γ

The relationship among the mixing ratio of two types of liquid crystal materials (LCM-1 and LCM-2), birefringence rate Δn and $|\Delta\epsilon|/\epsilon$, is shown in Figure 9. The Δn and $|\Delta\epsilon|/\epsilon$ change linearly against the mixing ratio and, when observed from the viewpoint of these two physical property values, it can be considered that steepness γ becomes the smallest when LCM-2 is 100 percent. Actually, however, the value of steepness γ is the smallest near the mixing ratio of 4:6, as shown in Figure 10. Therefore, it can be said that steepness γ is greatly dependent on the value of k_{33}/k_{11} . Since k_{33}/k_{11} does not generally change linearly against the mixing ratio of the two types of liquid crystal materials, it is necessary to pay attention when optimizing the liquid crystal material of VAN-type LCDs.

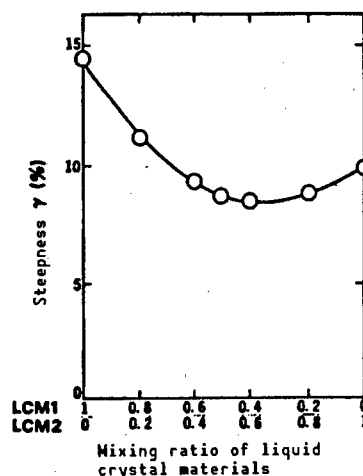
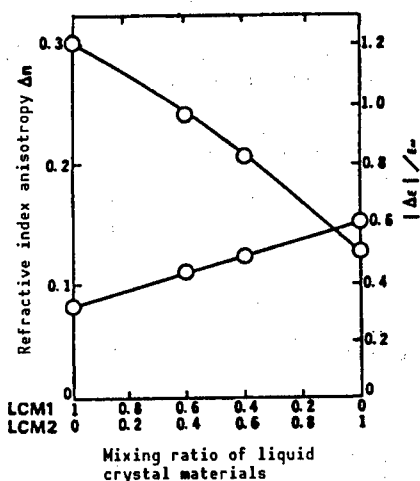


Figure 9. Relationship Among Mixing Ratio, Δn and $|\Delta\epsilon|/\epsilon$, Figure 10. Relationship Between Mixing Ratio and Steepness γ of Liquid Crystal Materials

3.2.4 Retardation $\Delta n d$, steepness γ , and visual angle dependency β

The changes in steepness γ and visual angle dependency β when making various changes to the cell thickness d and cell retardation $\Delta n d$ against the three typical types of liquid crystal materials with different composition systems (shown by $\square$, $\circ$, and Δ in the drawing) are shown in Figure 11. The value of steepness γ differs for each liquid crystal material but steepness γ becomes small when $\Delta n d$ is made large in all the liquid crystal materials.

On the other hand, the visual angle dependence β has no relationship to the type of liquid crystal material, but is solely dependent on retardation $\Delta n d$, and the visual angle dependence β deteriorates suddenly when $\Delta n d$ is great.

As seen above, the Δnd condition that improves the steepness γ characteristic and Δnd condition that improves the visual angle dependence β are in a trade-off relationship. Therefore, it is necessary to optimize Δnd from both the standpoints of contrast and angle of visibility, with the optimal range being $0.65 \mu\text{m} < \Delta nd < 0.85 \mu\text{m}$.

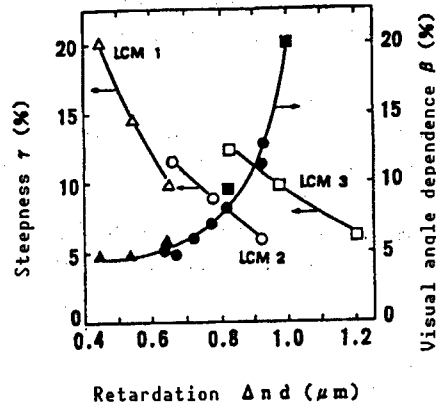


Figure 11. Relationship Among Δnd , Steepness γ and Visual Angle Dependence β

3.2.5 High speed and orientation instability phenomenon

It is extremely effective to make the cell thin when improving the speed of response. In the case of the VAN-type LCD with a thin cell, however, there are times when an instability generates in the molecular orientation when voltage is applied.

A photograph of an instability phenomenon of the molecular orientation generating in the display pixel when multiplex driving the VAN-type LCD with a cell thickness of $4 \mu\text{m}$ is shown in Figure 12 [not reproduced]. A domain with a different tilt direction is observed, and this becomes the cause of a drop in the contrast. Therefore, it is necessary to prevent this instability phenomenon of the molecular orientation.

The relationship among the cell thickness, drive frame frequency, operating temperature and instability phenomenon generation in VAN-type LCDs are shown in Figure 13. The generation of the instability phenomenon occurs in the oblique line domain of the drawing. In other words, it is known that the generation of the instability phenomenon is facilitated when the cell thickness is thinner, the drive frame frequency is lower, and the operating temperature is higher. This trend is the same as that of the ease of generation of the dynamic scattering phenomenon, and it can be conjectured from this fact that this instability phenomenon is a prodromal phenomenon of the dynamic scattering phenomenon.

Since the actual drive frame frequency is about 70 Hz from the demand from the drive IC, it is known from Figure 13 that the cell thickness at which an instability phenomenon does not generate at 50°C is greater than $5.5 \mu\text{m}$.

The molecular orientation instability generation method also changes according to the properties of the liquid crystal materials. We have discovered that the

generation of the instability phenomenon could be controlled by adding the chiral dopant to the liquid crystal material. The condition of instability phenomenon generation in VAN-type LCDs when adding this chiral dopant to the liquid crystal material shown in Figure 13 is shown in Figure 14. By comparing Figures 13 and 14, it can be seen that the addition of the chiral dopant has a great effect on the control of the instability phenomenon generation. When the chiral dopant is added, an instability phenomenon does not generate at 50°C up to a cell thickness of 4.5 μm and, therefore, the cell thickness can be decreased to 4.5 μm , making a high-speed LCD available.

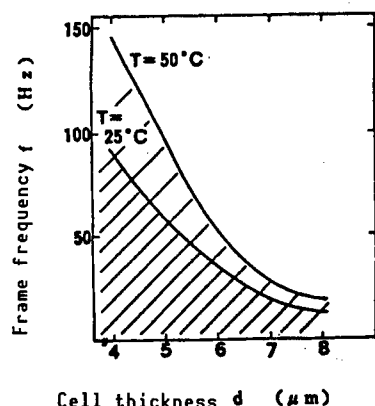


Figure 13. Relationship Among Cell Thickness d , Frame Frequency f , and Drive Temperature T Dependence of Instability Phenomenon Generation

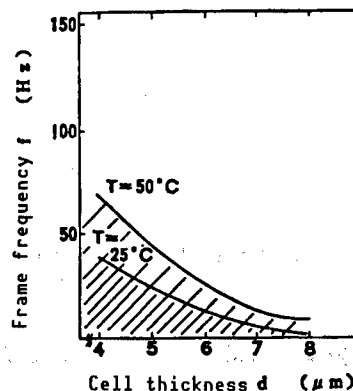


Figure 14. Cell Thickness d , Frame Frequency f , and Drive Temperature T Dependence of Instability Phenomenon When Adding Chiral Dopant

3.2.6 Expansion of angle of visibility by the compensating plate

When observing the VAN-type LCD from the oblique direction, such problems as the effective retardation becoming great when voltage is not applied, light being transmitted, and the angle of visibility becoming narrow are generated. The attempt to expand the angle of visibility by the addition of a compensating plate has been reported to resolve these problems.¹² In other words, there were the compensating plate in which a negative uniaxial optical film was sandwiched between a cell and polarizing plate, and the compensating plate which had optically sandwiched a biaxial film between the polarized plate and cell, one at a time. The latter is the composition in which a circular polarizing plate is placed in back and front of the cell. The visual angle dependence of the cell can be compensated for by these compositions, and the visual angle characteristics of the VAN-type LCD can be expanded.

3.3 Development of VAN-Type Color Video Display

Based on the study results mentioned above, the cell conditions of VAN-type LCDs have been optimized and a 12-inch diagonal color video VAN-type LCD has been developed.² The specifications and display performances are shown in Table 5. The number of picture elements is 320 x RGB x 256 pixels, and a RGB stripe color filter substrate in which ITO with a resistance value of less

than $15 \Omega/\square$ has been patterned is used. A monobasic chrome complex is used as the orientation agent, and the pretilt angle is about 0.5° . A hot cathode tube, matching the color filter with the spectral distribution, is used as the backlight. A pulse width modulation 16 gradation display liquid crystal driver, pressure proof for 28 V, is connected to the liquid crystal panel by TAB technology.

Table 5. Specifications and Display Performances of Color Video VAN-Type LCD

Display area	230(H) x 184(V) mm ²
Number of pixels	320 x RGB(H) x 256(V)
Color filter	RGB stripe
Contrast ratio	>30:1
Angle of visibility	Cone (CR > 3)
Response speed	50 ms
Gradation	16 gradations

In addition to the general top and bottom division drives, the multiple line continuous and simultaneous scanning method is used for the drive method. This drive method simultaneously addresses multiple lines continuing up and down and conducts driving by sliding one line each from top to bottom. Since the substantial driving duty ratio becomes large, there are improvements in the contrast and speed of response. However, care is necessary since the longitudinal direction resolution declines in this drive method. The two line continuous and simultaneous scanning method in which the decline in resolution does not become a substantial problem for the video display has been used in the color video VAN-type LCD this time. A drive of 1/64 duty ratio can be made, and a high contrast display with a contrast ratio of more than 30:1 and a high-speed response of $\tau_{on} = \tau_{off} = 50$ ms have been realized.

The CIE chromaticity coordinates of the display colors of the color video VAN-type LCD developed are shown in Figure 15. It can be seen that a color display of extremely high purity has been made available.

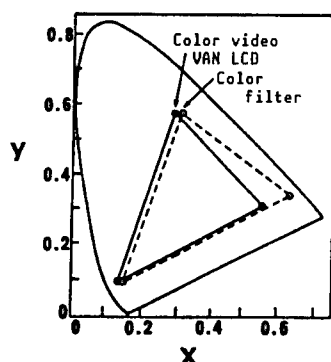


Figure 15. Display Colors of Color Video VAN-Type LCD

A display example of the trial manufactured color video VAN-type LCD is shown in Figure 16 [not reproduced].

Based on the study results mentioned above, a 640 x RGB x 480 pixel, 1/240 duty ratio drive multicolor display LCD has also been developed. A display example of the trial-manufactured multicolor VAN-type LCD is shown in Figure 17 [not reproduced]. A high contrast, wide angle of visibility, and clear color display is available. Great expectations can also be harbored in the application of VAN-type LCDs to OA equipment color displays.

4. Conclusion

Explanations have been made above regarding the newest technologies of the retardation system achromatic color ST-type LCD and VAN-type LCD. The retardation film system ST-type LCD not only excels in display performances, such as contrast ratio, brightness (transmittance), etc., but is also superior in thickness, weight, mass productivity, etc. It can be said to be the most advanced ST-type LCD currently available and, with the improvement and optimization of various characteristics of the retardation film used for this, the realization of a higher display quality RF-ST-type LCD can be expected.

Moreover, it is essentially an achromatic color display, and the simple multiplex drive color display to which the high contrast VAN-type LCD has been applied is able to exhibit practically symmetrical and wide visual angle characteristics, as well as providing a high contrast display with high color purity, and great expectations are harbored in its future development. The development and progress of liquid crystal materials with negative dielectric isomerism holds the key for the practical application and further improvement of display performances of the VAN-type LCD.

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Current Status, Future Trends of Active-Matrix LCDs

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[Article by Shinji Morozumi, Seiko Epson Corp.]

[Text] 1. Outline

1.1 Introduction

The importance of image display devices has come to be realized more and more in recent years. With the development of TVs and computers, expectations for higher minuteness, larger image plane, and compact and thin display devices are increasing. The appearance of the wrap top computer¹ and the high-definition television² trend are representative examples. The cathode ray tube (CRT), which had conventionally been the mainstream of image display, is not able to cope with these new needs due to its physical limits (especially volume and weight). On the other hand, the display capacity of flat displays, such as the liquid crystal, etc., has been remarkably improved and the attempt is being made for these to form the current of new electronics.

Among such flat devices, the active matrix liquid crystal display is attracting the most public attention. Differing from the simple matrix LCD, which scans and drives the dot matrix liquid crystal panel directly by the time sharing signal, there is no deterioration of picture quality, even when the number of scanning lines increases, since it is able to eliminate crosstalk. This is because the thin film active elements in each picture element block the crosstalk. As a result, a color image that compares favorably with that of the CRT has become available by liquid crystal for the normal TV or personal computer display.

1.2 Historical Development

As shown in Figure 1, the historical development of the active matrix LCD can be divided into the dawning age, searching period, the early commercialization age and the era of increased size.

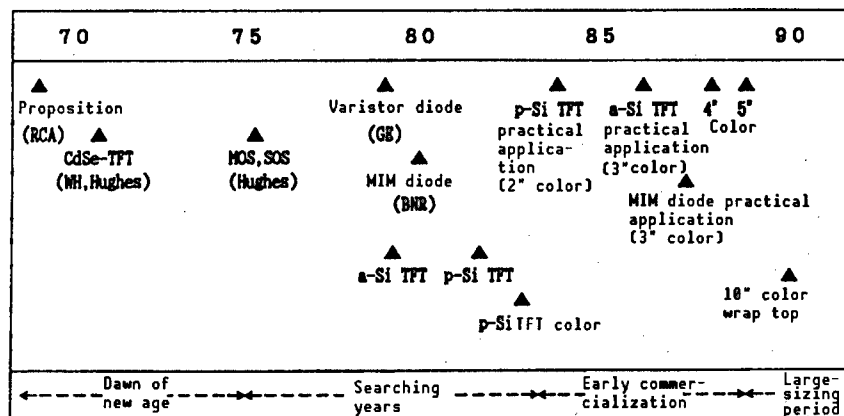


Figure 1. Historical Transition of Active Matrix Liquid Crystal Displays

Dawning Age

The active matrix concept was conceived by the Radio Corp. of America (RCA) at the same time the liquid crystal display was born, around the end of the 1960s.³ However, RCA, which had given priority to the development of TV, promptly put an end to research on these liquid crystals and, as a result, the R&D of these liquid crystals was transferred to Westinghouse Electric Corp. and Hughes.

Searching

The searching age during the first half of the 1970s refers to the searching for practical use active elements from the beginning to end.⁴ Research initially started in the United States with the TFT⁵ of CdSe, passed through silicon on sapphire (SOS)⁶ in the middle of the 1970s, and went up to the MOS transistor⁷ using the Si single crystal wafer. This MOS system was also adopted later in the compact (1-2 inch) black-and-white TV trial manufactured in Japan.^{8,9} Around the end of the 1970s, ZnO¹⁰ and MIM diodes¹¹ were also proposed in pace of the difficult-to-make transistors.

Early Commercialization

Commercializing the active matrix LCD has been brought about by Si-TFT. It is a polycrystal Si and amorphous Si. The hydrogenation technology of amorphous Si had already been developed in the 1970s and was applied to solar cells. The trial manufacture of TFT occurred around the end of the 1970s, but lacked stability.¹² Since the polycrystal Si thin film had been used as the gate electrode material of the MOS transistor, it could easily be applied to the TFT. The OFF current, which initially represented a major problem, was solved by controlling the film thickness, and the first practical active matrix LCD in the world, as well as the first liquid crystal color image, was born in 1983.¹³ This was the 2-inch liquid crystal TV. On the other hand, the stability problem of amorphous Si-TFT was solved by the introduction of the Si nitride film, and its practical use started similarly as that of compact liquid crystal color TVs. At the same time, the MIM diode also made its entry into this market by taking full advantage of its ease of production.

Large-Sizing Age

The active matrix LCD, which had steadily improved its production technology by establishing the compact TV image plane of less than 5 inches as the foothold, is now entering the period of full-scale application, i.e., the period aiming at the major market of more than 10 inches. The entrance product of this period is the color wrap-top personal computer. Various companies have dashed toward large-scale investment in the manufacture of LCDs directed at this market.

1.3 Merger With Semiconductor Technology

The problems with the active matrix LCD depend on how the active elements such as TFT, etc., are formed. The technology that played a major role in the formation of the active elements was the semiconductor technology used in integrated circuits. One contribution was the device technology which determines the structure and characteristics of the transistor, while another was the production technology which determines the process. Especially, since the basis of film accumulation, light exposure for pattern forming, and the etching process are common in the latter, full advantage has been taken of devices already completed for semiconductor use, handling, and other areas of expertise. Moreover, semiconductor experiences have also been extremely helpful for defect countermeasures which were very important in forming active elements. The projection exposure in the photo process and flake measures in the sputter and CVD devices could be easily appropriated by the development of the semiconductor technology. As seen here, the recent rapid development of the active matrix LCD in the 1980s has ultimately been greatly supported by the semiconductor technology, which has expanded and progressed to a great extent in the 1980s.

2. Current Status of Active LCD Technology

2.1 Thin Film Elements and Their Types

The active matrix LCD uses a glass substrate. There are two advantages when using a glass substrate. One advantage is that the substrate size restriction is small and the enlargement of the image plane is possible. The other advantage is that a high image quality twisted nematic (TN) can be used. The active element is formed by means of thin films when using a glass substrate.

The active matrix LCD is classified by the type of thin film elements used, but can generally be classified into two types—the three-terminal type (transistors) and two-terminal type (diodes). The panel composition of both types, in comparison with that of the simple matrix, are shown in Figure 2. Elements on a certain scanning line are turned ON only when both the three element and two element type are selected and the necessary display signals are received. Elements are in the OFF condition later during nonselection, and the display signal drives the liquid crystal accumulated in each picture element in an electric charge form. Therefore, since it differs from the simple matrix and since crosstalk during nonselection can be eliminated, the static characteristic of the TN liquid crystal mode can be reproduced with no dependence on the number of scanning lines. This is the principle of high

quality image display. However, the point is that the switching characteristics of the switching element, i.e., the resistance being quite low at ON and extremely high at OFF, are satisfactory.

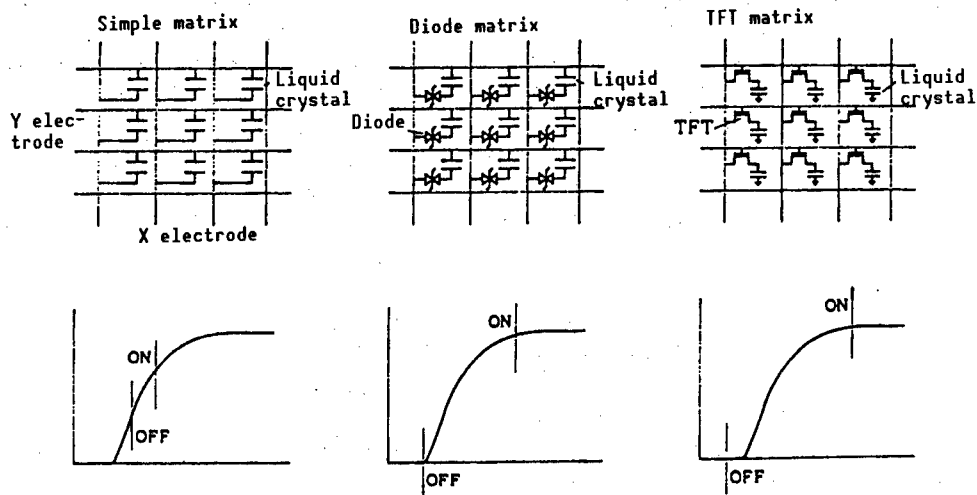


Figure 2. Composition of Dot Matrix LCD

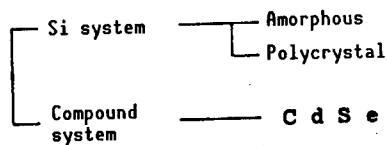
The switching characteristic in the case of the transistor (TFT) is simply expressed by the current ratio of ON/OFF, and a characteristic sufficient for switching is available with this value. However, the TFT production process is complicated and the defects are such that fabrication into a large area with few defects is difficult and the production cost is high. The method that has been devised for getting rid of these defects is the diode system. However, although a diode is simpler in structure than the TFT, the switching characteristic is generally inferior to that of the TFT. Therefore, the allowable steepness of the current threshold value characteristic becomes the key. Moreover, the allowable degree of characteristic uniformity is stricter than that of TFT.

The thin film element that has already been proposed and developed is shown in Figure 3.⁵ At the current stage, a total of three types of thin film elements has been put to practical use. They are amorphous Si-TFT and polycrystal Si-TFT for the three-terminal type, and the MIM diode by the Ta anode oxide film for the two-terminal type.

2.2 Thin Film Diode Matrix

The structure of the liquid crystal panel using the thin film diode is shown in Figure 4. The color filter layer (for a color display) and scanning electrode are configured on top. This is indeed the same structure as that of a simple matrix. On the bottom of the substrate is a data line consisting of metal wire, a transparent metal wire, a transparent pixel electrode, and thin film diodes connected between the two. One of the advantages of this system is that, as opposed to the TFT type, there are no wire crossovers, and short-circuits attributable to this can be avoided.

(1) Thin film transistor (TFT)



(2) Thin film diode

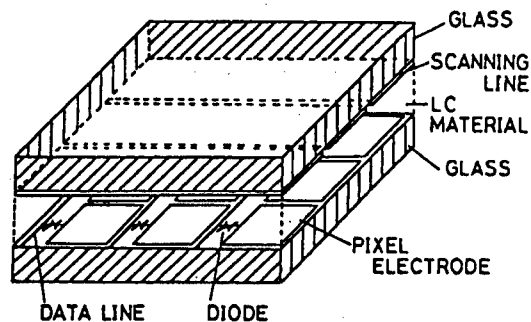
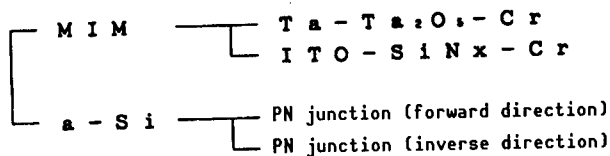


Figure 3. Types of Active Elements

Figure 4. Structure of Diode LCD

There are two types of thin film diodes, as shown in Figure 3. They are the MIM (metal-insulating film-metal) structure thin film diode and PN junction type thin film diode. The former utilizes the phenomenon in which the electrons move toward the electric field direction by going along the trap in thin insulating films, such as SiN,¹⁶ etc., and the bidirectional conductivity necessary for the liquid crystal drive is easily available. However, it is not easy to control the current in the insulating film to have good uniformity, reliability, and stability, and practical application has been limited to the system using the Ta anode oxide film.

The latter utilizes the PN junction of amorphous Si. However, since the threshold value of an ordinary PN junction is too low for a liquid crystal drive and is unidirectional, several devices have been proposed in the past. Although the system termed a ring diode¹⁷ that utilizes the forward direction (Figure 5(a)) has stacked diodes for earning the threshold value, the steepness of the current threshold value is lost. The back-to-back diode (Figure 5(b))¹⁸ utilizes the breakdown of the junction. It excels in steepness and threshold value, but lacks stability. There is also a type that uses two write lines for positive and negative polarities and which is now under development (Figure 5(c)). Figure 6 shows the structure of the MIM diode by the Ta oxide film actually used.²⁸ First, the data line wiring and bottom electrode of the element are formed by the Ta film. Then, the electric field is applied in the citric acid solution and an oxide film is formed on the Ta surface by the anode oxidation method. A Cr opposed electrode is subsequently attached to obtain a symmetrical characteristic with the pixel electrode of ITO, and the diode is completed. Advantages of anode oxidation are that the film thickness is determined solely by the applied voltage and there are no pinholes. Therefore, the characteristic uniformity is extremely good over a large area and elements without defects are easily available. The threshold value of this diode is a size of 10-20 μ m, both polarities are about 5 V and it is extremely convenient for driving the TN liquid crystal. Moreover, the equivalent ON/OFF ratio in the switching operation is about 10⁴.

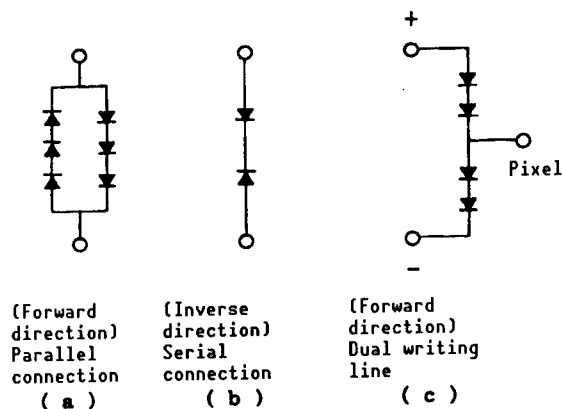


Figure 5. Actual Examples of PN Junction Diodes

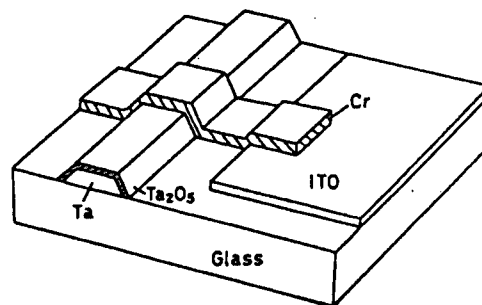


Figure 6. Structure of MIM Diode

2.3 Thin Film Transistor Matrix

The structure of the liquid crystal panel by the thin film transistor (TFT) is shown in Figure 7. TFT and all wires have been integrated in the bottom substrate, while the upper glass substrate contains the color filter and common electrode without a pattern. It is normal for a light-shielding layer, called the black stripe, to be provided in the pixel periphery and the top part of the TFT in order to emphasize the contrast and prevent the increase of the OFF current induced by the incident light. Moreover, there are times when the ideal operation is marred by the parasitic capacity with the gate wiring and data wiring when the electric charge of the pixel is only the capacity coming from the liquid crystal, itself. (Since the liquid crystal has high resistance, it is generally capacitive.) Therefore, an additional capacity is often provided for electric charge maintenance.

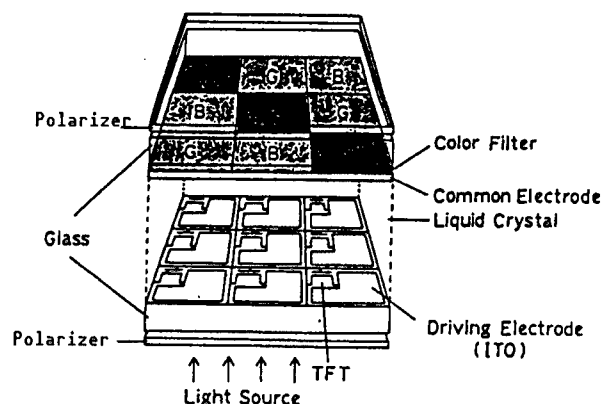


Figure 7. Structure of TFT-LCD

CdSe was well researched during the initial period as the material of thin film transistors; however, it now plays a minor role due to its OFF characteristic, stability, and the toxicity arising from the material, and putting it to practical use is said to be difficult. The nucleus is the Si thin film and

there are two types—polycrystal Si and amorphous Si thin films. Of course, although exceptional ones exist in the TFT structure, there are many stagger types having the gate electrode on top of the channel among polycrystal types and inverse stagger types with the gate electrode at the bottom among the amorphous Si types.

Since the amorphous Si-TFT accumulates film by means of plasma, forming is possible at about 300°C and it is optimum for forming on a large-area substrate. Amorphous Si-TFT of various structures has been proposed before. The representative structure²¹ among those proposed is shown in Figure 8. First, the gate wiring and gate electrode material of Ta, etc., are formed and then, three layers, consisting of SiN or SiON that becomes the gate insulating film true amorphous Si and SiN, which serve both as an etch stop and for passivation, are continuously grown by the plasma CVD method. Moreover, improvement of pressure proofness and defects should be made in advance by anode oxidizing the Ta surface. Then, etching is conducted by leaving the transistor domain, and the N-type amorphous Si forming the source drain is grown. Finally, ITO, which becomes the pixel electrode, the CR contact layer with the source drain, and the three metal layers of the Al wiring layer are formed by the sputter method. The characteristic of amorphous Si-TFT is that the dark current is low and, although it is of low mobility (about 0.5 cm²/V·sec) due to this, an ON/OFF current ratio of more than six digits that is necessary for operation can be secured. Moreover, the threshold value of TFT is about 1-2 V.

The characteristics of polycrystal Si-TFT are that mobility is high and the properties have been stabilized. However, it is necessary to select the glass material carefully since heat of about 600°C becomes necessary for crystallization. The structure of polycrystal Si-TFT is shown in Figure 9.

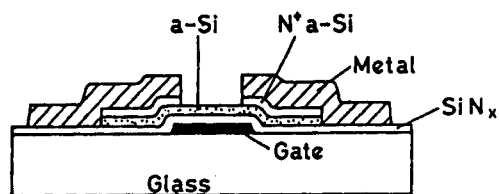


Figure 8. Structure of Amorphous Si TFT

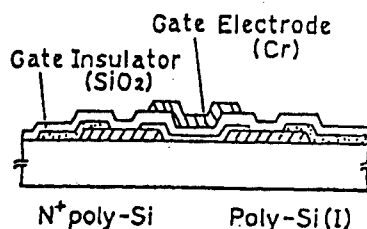


Figure 9. Structure of Polycrystal Si TFT

First, the true polycrystal Si island is formed in continuation of the N type, which is the contact layer, by the vacuum CVD method. Then, the gate oxide film is deposited by the CVD method and the gate wiring layer, oxide film between layers, ITO electrode, and Al wiring layer are formed. The OFF current is greater than that of amorphous Si, but an ON/OFF ratio of more than six digits is securable as the mobility is high (about 1 cm²/V·sec). Moreover, the threshold value is about 5 V.

The driver can be integrated with TFT that has been CMOS-ized by taking full advantage of the high mobility characteristic of polycrystal Si-TFT.²² The mass production of small panels has already been made. Attempts to greatly improve

the TFT characteristic for larger or higher resolution panel drivers are being conducted. A mobility of 30 has been obtained for the N channel burying a trap by plasma treatment. In addition, the realization of mobility approaching 100 is also possible by allowing the crystals to grow.

3. Application and Future of Active LCD

3.1 Application Fields of Active LCD

Applications of active matrix LCD, that have been put to practical use at the present stage and those that are close to practical application are shown in Figure 10. The polycrystal Si-TFT is mainly used in the small-sized division of less than a 3-inch panel size, i.e., those that are used for monitor and projection displays of video cameras. On the other hand, the amorphous Si-TFT and MIM diodes are used for compact 3-5-inch color televisions and projection displays. Based on the positive production achievements of comparatively small panels, we want to apply these thin film elements to the data terminals of color wrap-top personal computers, etc. The critical point drawn from Figure 10 is that the 10-30-inch applications, in which CRTs are at their best, are being avoided for the time being. When the market scale expands, as explained below, this fact will basically mean nothing except for the creation of a new market by the liquid crystal itself. In other words, the current growth of the liquid crystal is not meant to replace the CRT.

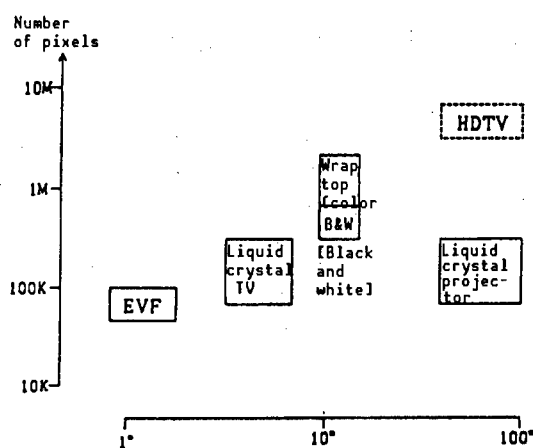


Figure 10. Application Fields of Active LCD

Application to Direct-Vision TVs

Image quality is the important characteristic of a television and in that regard the active matrix plays a central role. However, there is currently no large picture plane that can be installed in domestic living rooms. There may not be the practical application of the high definition wall hanging television within the next five years. Therefore, the small picture plane of around 5 inches will be the mainstream for the time being. The market of small liquid crystal televisions is not very large, but when the cost of the panel becomes cheap enough, they will be routinely incorporated in video decks, radio cassettes, and audio sets, and the market will explode.

Application to Computers

The liquid crystal is the mainstream for monitors which require miniaturization, such as the wrap-top personal computer. It is advantageous to the active matrix from the standpoint that a high image quality, although high in cost, is demanded, especially in the color display for people's livelihood products such as televisions. The market will expand considerably in the future due to the fact that the wrap-topping of personal computers will be accelerated, and it will become the tractive force of the liquid crystal. Moreover, when a high resolution is realized, it will likely diffuse not only to wrap-top personal computers, but also to general terminals.

Projection Display

The enlargement of home television picture planes is demanded. This demand is especially strong in the high definition TVs premised on large-sized picture planes. However, it will be difficult to realize the 40-inch CRT for home use. On the other hand, the immediate realization of the direct-vision type LCD is also difficult. Speaking in terms of this, the liquid crystal projection system is capable of simultaneously realizing the enlargement of the picture plane and miniaturization of the set.²³ Since a high image quality is demanded, the TFT-LCD is used for the light valve. It is predicted that a market for a screen exceeding 50 inches for home use, including the replacement portion of the CRT projector, will arise.

3.2 Topics and Future Development of Active LCDs

The transition estimate of the annual production sum for liquid crystal panels in Japan is shown in Figure 11. The main fields of growth in the future are the field for the 10-inch class data terminals of wrap-top personal computers, etc., and the field for compact image displays (including projection display panels). It is expected that the active matrix LCD will represent the tractive force in both of these fields. However, this prediction is premised on the fact that progress will be made while the serious problems which the active LCD possesses are solved to a certain extent.

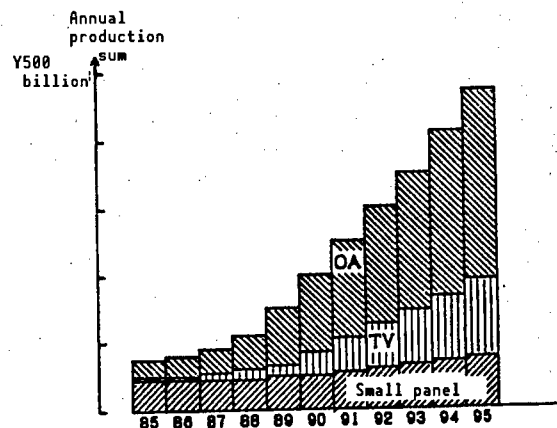


Figure 11. Market Estimate of Liquid Crystal Displays

The biggest topic is cost reduction. Although increasing the production yield is made the premise, an enormous investment is attached to production. This is because the production process is extremely complicated and the substrate size is large. The basis of production equipment up to now has been for semiconductors. However, although the pursuit of fining, rather than the processing area, was the goal for semiconductors, the expansion of the processing area with the design rule fixed is the future direction for the active matrix LCD. Therefore, the development of a device exclusively for use with the active LCD, capable of processing a large substrate with high quality and high throughput, will become the key from now on.

At the same time, the simplification of the structure and process of the active elements is necessary. A comparison of the amorphous Si-TFT, polycrystal Si-TFT and MIM diode is shown in Figure 12. MIM diode production takes about half the processing of TFT and the substrate production cost is also one-half. However, the switching characteristic is insufficient, and the improvement of this point is crucial. Since the incorporation of the circuit is possible in the polycrystal Si-TFT, the driver cost can be reduced. However, there remains a problem with enlargement. At the present stage, it would be hasty to decide which element will eventually satisfy both cost and performance. However, efforts to develop elements with higher production efficiency and investment efficiency are necessary.

	MIM diode	a-Si TFT	p-Si TFT
Element fabrication			
Photomask	2~3 + 1	5~6	5
Temperature	450°C	350°C	600°C
Deposition	Sputtering	p-CVD	LPT-CVD
Performance			
Contrast ratio	70:1	100:1	100:1
Viewing Angle			
L/R	+50° (5>1)	+60° (5>1)	+60° (5>1)
U/D	45°/20°	40°/30°	40°/30°
Temperature range	0°~50°C	0°~80°C	0°~80°C
Gray scale	16~32	>16	>16

Figure 12. Comparison of Active Elements

The resolution of the topics mentioned above is not impossible physically, but is considered to involve a problem of time. As a result, the active matrix liquid crystal display is expected to grow as a device supporting the electronics which will follow conductors.

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Active Matrix (2)-TFT Addressed Active Matrix Liquid Crystal Display

906C0054D Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 37-46

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[Text] 1. Introduction

The recent progress of flat panel displays has been spectacular. The liquid crystal display is ultimately the nucleus of flat panel displays, and the development of an active matrix display using TFT has been promoted at a particularly high pitch recently.

With the progress of these developments, the wall hanging TV that had only been dreamed about has come close to being realized. Moreover, even the impetus of approaching the CRT stronghold, which had dominated the display market for close to 40 years, is being felt. The 1990s will become the age of flat panel displays. In addition to the liquid crystal flat panel displays, include the plasma (PDP), EL, light emitting diode (LED), flat CRT, etc., which are all light emitting type displays. The liquid crystal is a non-light-emitting type display and works as a display without an external light. However, there is a freedom of external light wavelength selection and it is suitable for coloring.

On the other hand, the history of TFT is old. It was in 1961 when P.K. Weimer (RCA) prepared the first thin-film transistor by using CdSe.¹ Weimer and his group first applied this transistor to a solid-state image device. It was T.P. Brody and his group (Westinghouse) that strenuously promoted its application to displays,² and they successfully trial manufactured the TFT-LCD panel in 1978.³ In 1979, the operation of a-Si TFT was first reported by W.E. Spear, et al., at Dundee University.⁴ With this announcement as the turning point, the application of a-Si TFT to liquid crystal displays was energetically promoted. Japanese manufacturers started the trial manufacture and product development together, with the 3-inch liquid crystal television appearing on the market in 1987. After this, the 5-inch liquid crystal television appeared on the market in 1988, the 6.3-inch liquid crystal television in 1989, and the 10-inch liquid crystal television appeared in 1990, with commercialization announcements being made one after another. The composition of the active matrix liquid crystal display using a-Si TFT is shown in Figure 1. The transmittance of the liquid crystal is controlled by inserting a TN (twisted-nematic) liquid

crystal between the TFT glass substrate and color filter glass substrate and applying a signal voltage between the common electrode and pixel electrode. Since the light granting property of light is utilized in this control, a polarizing plate is placed on both sides of the liquid crystal panel. Explanations will be made below on TFT and the structure and characteristics of liquid crystal displays using TFT.

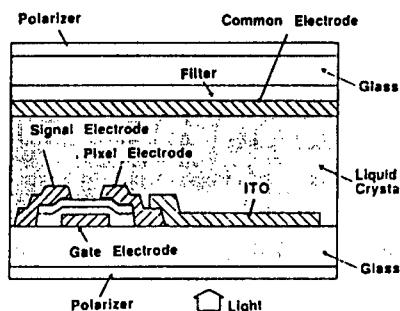


Figure 1. TFT Liquid Crystal Display

2. Thin Film Transistor

In the active matrix display, an active element is installed for each pixel of the display panel, and the voltage applied to the pixel electrode by this points to the controlled display. Active elements can be classified into two terminal elements and three terminal elements, but the explanations made here will be limited to the thin film transistor (TFT), which is a three terminal element. Materials used for TFT include CdSe, Te, polycrystal silicon and amorphous silicon, and many reports have been made on each. This discussion will focus on the silicon system TFT that is currently in general use.

2.1 Polycrystal Silicon TFT

The characteristic of the polycrystal silicon (poly-Si) TFT is the mobility height. It can approach the mobility of a single crystal silicon when the process temperature is high. When quartz is used for the substrate, a high temperature process exceeding $1,000^{\circ}\text{C}$ is also possible, and the mobility also reaches several hundred $\text{cm}^2/\text{V}\cdot\text{sec}$.⁵ Since the quartz substrate is high in cost, studying the low temperature process using an inexpensive glass for the substrate has recently become the mainstream. The guidelines for the low temperature process include a temperature less than 650°C , for which the available mobility value is $30\sim 40 \text{ cm}^2/\text{V}\cdot\text{sec}$. This value is between those obtained by amorphous silicon and crystal silicon. However, the trial manufacture of TFT by laser annealing is also being conducted.

The lasers used are the Ar laser and XeCl excimer laser. The structural cross section of poly-Si TFT is shown in Figure 2. A polycrystal silicon is deposited on the substrate by the vacuum CVD method and is processed to an island shape since the mobility of poly-Si TFT is great, the possibility exists of incorporating the drive circuit in a glass substrate shape. Trial manufacture examples reported include comparatively compact panels.⁶ It will be necessary to attain a mobility of more than $100 \text{ cm}^2/\text{V}\cdot\text{sec}$ in order to cope with enlargement and high fining. At the same time, the reduction of the threshold voltage and OFF current is also an important topic.

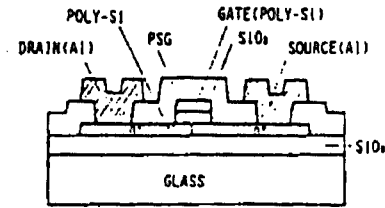


Figure 2. Cross Section of Polycrystal Si TFT

2.2 Amorphous Silicon TFT

The study of the application of amorphous silicon (a-Si) TFT to displays was started practically at the same time as that of poly-Si TFT. Amorphous silicon has the following characteristics:

- 1) Large area realization is possible (more than 20 inches).
- 2) It is obtained by a low temperature process (around 200~300°C).
- 3) It excels in uniformity and reproducibility.
- 4) The freedom degree of the substrate selection is great.
- 5) Fine processing is possible.
- 6) There is no toxicity.
- 7) The specific resistance is high, but doping is easy.
- 8) Preparation of the heterojunction is easy, and the interface characteristic is superior.

These characteristics have exhibited a great effect on large area realization (Nos. 1, 2, 3, 4), high fining (Nos. 3, 4, 5), and high yield (Nos. 2, 3, 7, 8). Moreover, since a-Si has a high specific resistance, the OFF current of TFT is controlled at a low level and the consistency with liquid crystals having similarly high resistance is good. The mobility is $\mu \sim 1 \text{ cm}^2/\text{V}\cdot\text{sec}$ and lower, but it has an ON current ($\sim 1 \mu\text{A}$) sufficient for driving the liquid crystal. One of the great characteristics of a-Si is that its photoconductivity is high. This characteristic has already been demonstrated through applications to solar cells and electronic photos, but it is not a characteristic desirable for displays. This is because a light current flows and the OFF current deteriorates when it is subject to lights (backlight, etc.). Countermeasures are being taken by covering it with a light-shielding film and making the a-Si film thin. This is attributable to the instability of the interface of the a-Si and gate insulating film. Stabilization is being promoted by the optimization of the TFT structure and process conditions.

a-Si TFT Structure

The cross section of a-Si TFT having an inverse stagger structure is shown in Figure 3.⁷ Patterning is made after depositing Cr as the gate electrode. Then, film forming of SiN as the gate insulating film, undoped a-Si as the channel layer, and the n^+ layer as the ohmic layer is made on top, in order, by the plasma CVD method. After forming the a-Si island domain by etching, Cr/Al is deposited for the source-drain electrodes by sputter vacuum deposition, and patterning is made. This becomes the mask, and etching off of n^+ a-Si on the a-Si channel is conducted. Finally, the SiN protective film is deposited.

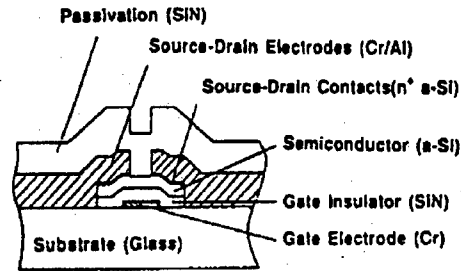


Figure 3. Cross Section of a-Si TFT

The preparation procedure of the inverse stagger structure has also been changed.⁸ After patterning the gate similarly to the example shown in Figure 3, the SiN/a-Si/SiN film is deposited. In other words, after first preparing the channel upper part protective film, n+a-Si is deposited for the ohmic contact. The characteristics of this system are that the a-Si layer is not damaged since etching on the channel top part is not necessary, and it is advantageous for light current reduction since the a-Si film can be made thin.

The stagger structure a-Si TFT⁹ has also been put to practical use. The a-Si is on the gate electrode in the inverse stagger structure, but this becomes reversed in the stagger structure, with the gate electrode on top of the a-Si. The gate electrode also serves to shield the light coming from the bottom in the inverse stagger structure, but a shielding film must be provided separately at the beginning of the process in the stagger structure. On the other hand, it is necessary to shield the light coming from the top part in the inverse stagger structure. The method of providing a black matrix on the color filter substrate side and serving it as a light-shielding film as well is effective.

Characteristic of a-Si TFT

The characteristic of the a-Si TFT is shown in Figure 4. This demonstrates the relationship of the gate voltage and drain current, a high ion current, and low OFF current have been realized, and a high ON/OFF ratio of more than eight digits is available. An ON/OFF ratio of more than 10 digits can be realized at the laboratory level. The threshold voltage is also low, and the inclination of the subthreshold domain is 0.3 V/decade and good.

One of the topics involving a-Si TFT is the V_t drift. There is a gate voltage dependence, with the dependence differing according to the positive and negative gate voltages. This state is shown in Figure 5. The amount of drift (ΔV_t) is greater for the positive voltage application side in the low voltage domain. This is the advantageous direction when considering the panel operation, because the duty ratio applying positive voltage to the gate is low. The duty ratio becomes $1/N_o$ of scanning lines of the display panel. The display life can be estimated by checking the voltage dependence, time dependence, and temperature dependence of TFT and by interpolating these.⁷ The drift amount of V_t is dependent on the fabrication conditions of TFT. For example, the greater the flow rate of the N_2 and NH_3 gas, the better when depositing SiN. Moreover, it is preferable if the deposition temperature exceeds 300°C.

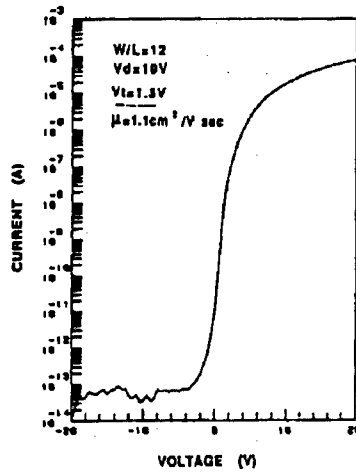


Figure 4. Relationship Between Drain Current and Gate Current of a-Si TFT

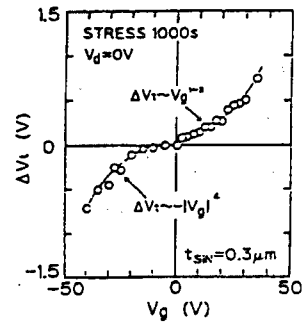


Figure 5. Drift Voltage

A life of more than 10,000 hours is available in TFT when ΔV_t has been minimized. These values are sufficient for normal use.

The characteristic of a-Si TFT can be described well by the following equation of the current-voltage used in MOSFET (metal-oxide semiconductor field effect transistor).

- 1) In the range of $V_d < V_g - V_t$

$$I_d = \mu \frac{W}{L} C_i \left[(V_g - V_t) V_d - \frac{V_d^2}{2} \right] \quad (1)$$

- 2) In the range of $V_d > V_g - V_t$

$$I_d = \frac{1}{2} \mu \frac{W}{L} C_i (V_g - V_t)^2 \quad (2)$$

Here, W = channel width, L = channel length, and C_i = gate insulating film capacity per unit area. Strictly speaking, since a-Si differs from crystal silicon and possesses a gap inner level, this point must be taken into consideration. The result of numerical simulation conducted by taking into consideration the level density, as shown in Figure 6, is shown in Figure 7. The coincidence of the experimental and calculated values is good.

3. TFT Liquid Crystal Panel

The composition of a liquid crystal panel using TFT is shown in Figure 8. The liquid crystal is shown by capacity in this drawing, but it is normal for the capacity to be connected in parallel with the liquid crystal in order to improve the maintenance characteristic of the panel. There are two composition methods for capacity. These composition systems are called the storage capacity method and added capacity method. The storage capacity is formed by providing a separate electrode opposing the pixel electrode, which is pulled out externally and is connected in common.⁸ On the other hand, the added

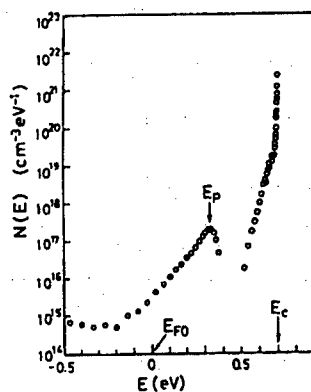


Figure 6. Energy Dependence of Gap Inner Level $N(E)$ of a-Si

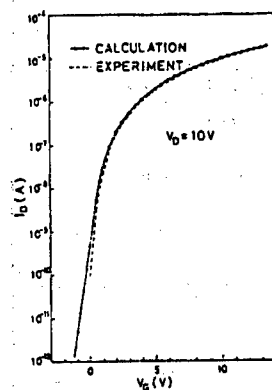


Figure 7. Computer Simulation of a-Si TFT Characteristic

capacity methods⁹ forms a capacity between the pixel electrode and next step (preceding step) gate line, as shown in Figure 8. The process is simple for the added capacity method since a special process is not necessary for forming the capacity. However, since it is linked to an increase of the gate line capacity, it can cause gate line delay. Nevertheless, the resistance of the gate line is reduced and this portion works advantageously. On the other hand, although the influence on the gate line delay is small in the storage capacity method, the process is generally complicated since the transparent electrode (ITO) is involved.

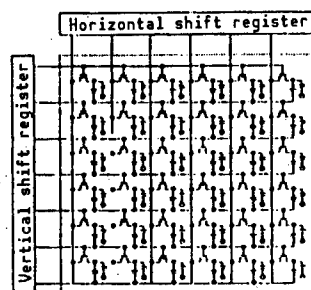


Figure 8. Composition of TFT Liquid Crystal Panel

The selection of the metal to be used for the gate bus line effects gate delay. It is normal for Cr to be used as the gate electrode of the simple TFT substance. However, the gate delay of the bus line by Cr increases independently when enlarging and high fining progress, and a countermeasure becomes necessary. Its resistance is lowered by using Cr in the TFT part and Al in the bus line part. Studies have also been reported in which Mo-Ta¹⁰ and Cu were used in place of Cr. The gate line capacity also has a relationship with the gate delay. It is important to minimize the intersecting area of the gate bus and drain bus.

Various measures have been conducted to improve the panel yield. The adoption of the redundancy system is one of these measures. Studies on the multiplexing of TFT and pixel electrode have progressed. The multiplexing of TFT provides multiple TFTs for each pixel and is intended to cut off the defective TFTs.¹¹

The drive capacity of the pixels drops to $(N-1)/N$ (N is the number of pixel TFTs), but is permissible as long as it remains in the allowable range. Since the numerical aperture decreases as a matter of course in the redundancy design, it becomes a trade-off with yield improvement. The method of partitioning the pixel electrodes is intended to not cut off the defective TFTs.

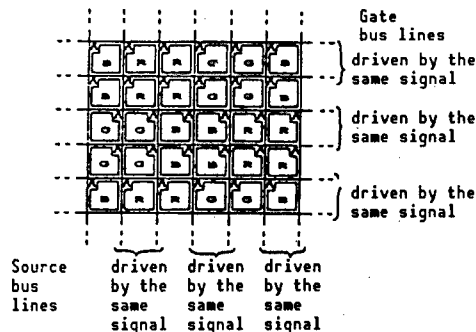


Figure 9. Four-Partition Pixel Panel

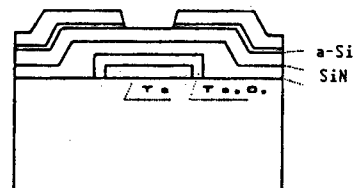


Figure 10. TFT Using $\text{Ta}_2\text{O}_5/\text{SiN}$ Two-Layer Gate Insulating Film

An example of the four partitioned pixels is shown in Figure 9.¹² The disconnection and short-circuiting of bus lines are observed to lower the panel yield. Since the TFT panel forms the gate bus line and signal line bus line on the same substrate, layer shortcircuiting becomes a fatal defect (line defect). Since the structure of the TFT part is especially complicated, layer shortcircuiting is facilitated. The double layering of the gate line is conducted to prevent this. A good example of the $\text{Ta}/\text{Ta}_2\text{O}_5$ system is shown in Figure 10.¹³ In one method, Ta is used for the gate electrode and is then anodic oxidized and made into Ta_2O_5 , while in another method Ta_2O_5 is formed by sputtering, etc. SiN or SiO_2 is formed on top of this and the gate insulating film is double layered. Since the formation of Ta_2O_5 by anodizing is a wet process, few defects are generated in comparison with the dry process. Moreover, since the dielectric constant of Ta_2O_5 is high (~ 24), it has the advantage of increasing the mutual conductance of TFT. However, it is necessary to use a separate metal for the gate bus line since the specific resistance of Ta is at about the same level as that of Cr.

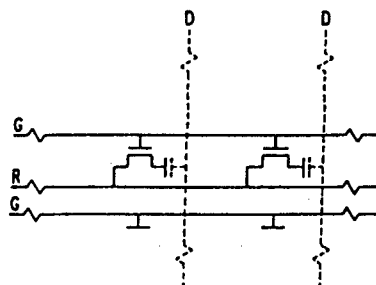


Figure 11. TFT Panel Composition Without Metal Wire Crossover

The unique method for eliminating short-circuits between gate signal lines involves conducting gate wiring and signal wiring on a separate substrate. In other words, the gate wiring is made on the TFT substrate and signal wiring is made on the filter substrate side (Figure 11) and, theoretically, short-

circuiting is not generated.¹⁴ However, the problem of crosstalk remains, and it has not yet been put to practical use.

This does not represent a problem with the simple TFT substance, but the generation of a DC current by Cgs does become a problem in the display panel.¹⁵ The generation of a DC current in the TFT panel is shown in Figure 12. An AC voltage is applied to the display panel liquid crystal, but an offset is generated in this AC voltage due to the Cgs effect. Since this offset voltage exerts an ill effect on the liquid crystal display characteristic, the smaller, the better.

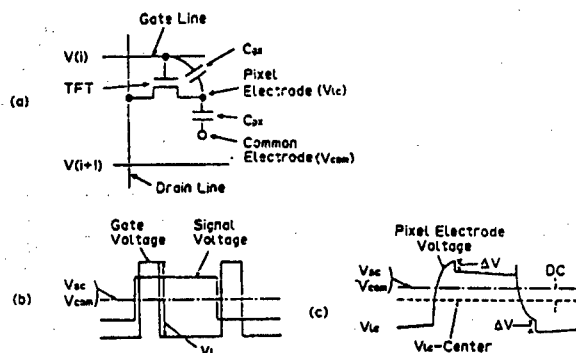


Figure 12. Generation of DC Current in TFT Panel

Panel Process

Six to eight masks are the standard for the TFT process in the case of a-Si. The outline is shown in Figure 13. The metals and ITO are deposited by the sputter method, and a-Si, SiN, SiO₂, etc., are deposited by the plasma CVD method. There is nothing here that is especially novel technically speaking, but devices have become larger since it was necessary to cope with enlargement, and the uniformity and reproducibility of film thickness, film quality and interface characteristics have come to be demanded more strictly.

Deposition	Material	Function
Sputter	Cr	Gate
P-CVD	SiN a-Si(i) a-Si(n)	Insulator Semiconductor Ohmic contact
Sputter	Cr Al	Source and drain
Sputter	INTO	Transparent electrode
P-CVD	SiN	Passivation

Figure 13. a-Si TFT Panel Process

The enlargement of the spinner and exposure device is urged in accordance with the larger substrate. It is comparatively easy to prepare CVD and sputter devices of the 1 m ϕ class, but a breakthrough is necessary for the exposure device. Even the largest exposure device currently available has a diagonal of 18-20 inches. The commercialization of a 10-14 inch diagonal panel is the target for the time being due to the relationship with the throughput.

Display Characteristics

Luminous intensity, contrast, visual angle dependence, response characteristics, etc., can be listed as panel display characteristics. The thing that first determines these characteristics is the liquid crystal, followed by the TFT, color filter, and backlight.

The numerical aperture of the backlight and TFT, the numerical aperture of the black mask, etc., determines the luminous intensity and, since the transmittance of the liquid crystal panel is around 5 percent when the polarizing plate is included, about 2,000 lux is necessary for the luminous intensity of the backlight. The contrast, visual angle dependence, and response characteristics are mainly determined by the liquid crystal. They are also dependent on whether the liquid crystal is normal white or normal black. The contrast can be greater for the normal white, which becomes a white display when voltage is not applied. This is because it is possible to sufficiently eliminate black sinkage.

The visual angle dependence differs according to whether it is up and down or left and right. Generally, the left to right visual angle is wider and, although there is no set definition for the visual angle, making it an angle which is one-half of the contrast maximum, or an angle in which the contrast is 10, etc., is considered. The response time differs according to the rise and fall, but the fall is generally slightly faster. Both response times are several dozen meters. The response time is in inverse proportion to the square of the liquid crystal film thickness and becomes fast. The printing phenomenon is also one that is entwined with the liquid crystal response. It is a phenomenon in which the pattern remains after having been erased when the same pattern is left displayed for a long time. The physical elucidation of the phenomenon is not necessarily clear, but is related to the DC current applied to the liquid crystal. The relationship between the DC voltage and printing time of the liquid crystal is shown in Figure 14. The DC current has been offset by the CBC method¹⁶ shown in Figure 15.

This method is synchronized with the pulse application to the selected gate line, applies an opposite polarity pulse to the next step added capacity (Cadd) and eliminates the gate pulse effect. The offset condition is shown by the following equation:

$$Cadd = Cgs \frac{V_1}{V_2} = \quad (3)$$

Here, V_2 is the amplitude of the offset pulse.

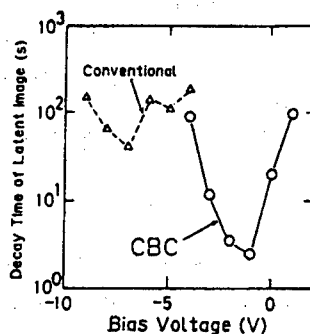


Figure 14. Reduction of Burning by CBC Method

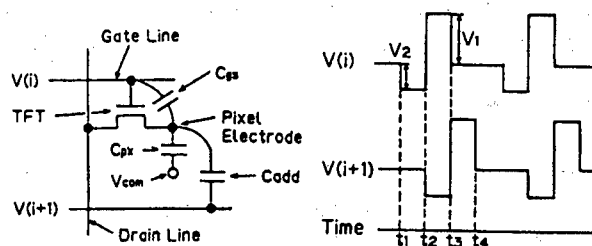


Figure 15. DC Voltage Offsetting Method of Liquid Crystal Panel

The characteristic of the liquid crystal is determined by the liquid crystal film thickness d and the difference Δn of the birefringence ratio, and it is normal to make the product of both as follows. The orientation film also exerts a delicate effect on the display characteristics.

$$\Delta n \cdot d = 0.5 \sim 0.6 \quad (4)$$

The reproducibility is determined by the color filter. It has practically the same color reproducibility as CRT. The apparent resolution increase, luminous intensity increase, etc., can also be promoted by the color filter configuration. Several color filter compositions are shown in Figure 16.

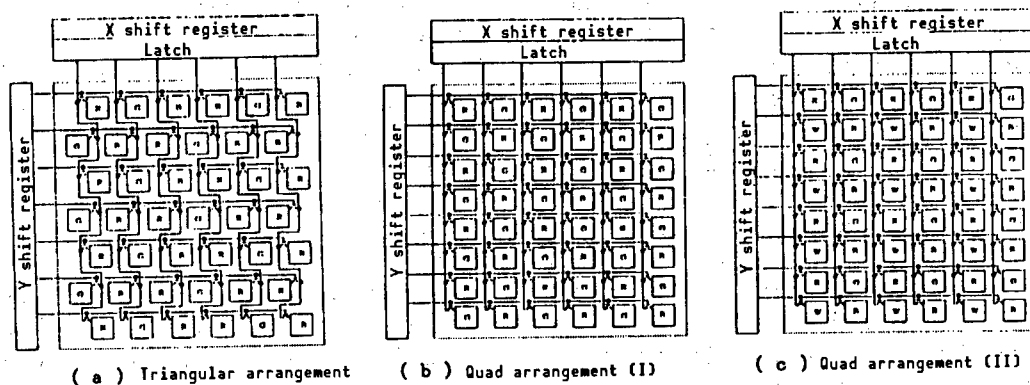


Figure 16. Color Filter Composition

Drive Circuits

The module composition including the TFT display panel is packaged and uses vertical and horizontal drive circuits on the outer side of the panel. Many ICs of the TAB (tape automated bonding) system are used for the packaging. The anisotropic conductive film is used for bonding (outer lead bonding) with glass. The shortening of pitch between leads represents a problem in this case. The bonding of about 5-6 each/mm is used on a practical basis, but a higher densification is not necessarily easy. This remains as a future topic.

On the other hand, the COG (chip on glass) method, which bonds an IC chip directly on a glass substrate, has also been studied. However, it is not as simple as had initially been expected since the size of the chip itself does not become very small and since a process for the terminal electrode on the TFT substrate becomes necessary. Repairing defective chips is also one of the topics.

Built-in drive circuits will also become possible when the realization of high performance poly-Si TFT progresses. The trial manufacture of built-in vertical circuits by a-Si TFT has also been reported.¹⁷

4. Applications of TFT Display

The application of TFT displays started with the liquid crystal television. It initially started with the diagonal size of 2 inches, but 5-inch TFT televisions have now appeared on the market. In the past year or two, not only televisions, but also composite merchandise docking with VTRs, have appeared. Differing from television, VTR playback is not affected by radiowaves. Wrap-topping has also progressed, as have applications for vehicle loading. There is also the possibility that navigation applications for automobile use will become a major market. Applications also exist for seatback televisions and the displays of aircraft, Shinkansens, and various special express trains. The audio entertainment in planes and trains will soon be replaced by AV entertainment.

However, the greatest application field will be the OA (office automation) field. TFT displays will equip OA equipment such as the WP, PC, WS, etc., in the near future. In addition to the 6.3-inch TFT television that is currently on the market, the 10-inch class TFT televisions will appear on the market in succession beginning this year. The CRT size for practical use in the wrap-top and desk-top equipment ranges from 12~14 inches. These CRT sizes correspond to the 10~12 inch liquid crystal displays. It is expected that the market related to these products will explode in the future.

Enlarging the image plane becomes the key point in liquid crystal television applications. It would be interesting to know how large direct-vision displays will become, but it is believed that it will be segregated from the projection. The current limit is 20 inches, but it will become larger in the future. High fining is also an issue, and the liquid crystal EDTV and HDTV era will also arrive.

5. Conclusion

A sudden increase in the market for TFT displays can be expected in the future which, with the forecast for 1995, is said to represent a ¥700 billion market. In order to catch up, the facility investment alone will amount to an enormous sum, and it appears that we will move from the age of rivalries to the age of crystal domination. In any event, it will march on the citadel of the CRT in several years and, moreover, passing the CRT is not altogether a dream. It is certain that a drastic renovation of AV equipment among household electric appliances will be brought about by this, and personalization and portability will also be spurred also in the OA environment (Table 1).

Table 1. Key Words of TFT Display

Points	Products
Personal	Personal computer
Portable	Portable TV
Plug free	word Processor
low Power	Pocket TV
flat Panel	Panel display
Projection	Projection TV
Poly-dimension	CPU terminal
Profitable	Paperless office
Plus α	
small Package	

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Liquid Crystal Projection Display

906C0054E Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 47-52

[Article by Masakazu Yamamoto, TV Systems Division, TV & Video Systems Group, Sharp Corp.]

[Text] Summary

Employing liquid crystal technology, we have developed a projector that is completely different from existing CRT systems. The projection system uses three newly-developed, 3-inch monochrome TV system TFT active matrix LCD panels. The light source is a high-intensity, high-efficiency metal halide lamp that provides good color rendering and consumes very little power. Moreover, the white light of the light source is divided/combined using a dichroic mirror, realizing a wider range of color reproduction than CRT displays. In addition, the device employs a zoom lens, so one can freely choose screen sizes from 20~100 inches. It is possible to reduce the picture size by up to 50 percent without changing the projection distance.

This brief report is intended to describe the fundamental aspects of the projector, the makeup of the projection system, and to give a brief account of the projector performance.

1. Introduction

High image quality and large picture planes have come to be directed toward the popularization, diversification, and fulfillment of AV media in recent years. We have applied the liquid crystal technology to an entirely new image equipment, miniaturization, and weight reduction, which were difficult to realize in conventional direct-vision type displays and projection type displays by the Braun tube, are being promoted, and an image system in which a large image plane can be readily enjoyed has been realized.

2. Outline of Announcement

As an application of liquid crystal technology, a liquid crystal projector was developed as new image equipment entirely different from the conventional Braun tube system. This device employs three 3-inch monochromatic panels of the TN-type TFT active matrix system that were newly-developed for projection

and adopts a metal halide lamp of high-intensity, high-efficiency, low electricity consumption, long life, and high color rendering for the light source. Furthermore, the white color of the light source has been divided and combined by the dichroic mirror, and a color reproduction wider than that of the Braun tube has been realized. In addition, screen sizes of from 20 inches up to 100 inches can be freely selected by the adoption of a zoom lens, and it is possible to reduce the picture size up to one-half without changing the projection distance. Reports will be made on the display principle of the liquid crystal projector, as well as on the composition and performance of this device, in this report.

3. Advantages and Disadvantages of Projector

The following have often been used as conventional methods for promoting large display screens.

- Direct-vision-type display by Braun tube
- Projection-type displays by Braun tube
 - Front system
 - Rear system

The following systems have appeared due to the remarkable progress made recently in liquid crystal technology.

- Projection-type displays by liquid crystal
 - Front system
 - Rear system

Table 1. Comparison of Various Displays

	Braun tube, direct vision type	Braun tube, projection type		Liquid crystal tube, projection type	
		Front system	Back system	Front system	Back system
Large screen	x	o	Δ	o	Δ
Setting space	Δ	o	Δ	o	Δ
Weight	x	Δ	x	o	Δ
Image quality	o	o	o	Δ	Δ
Main body size	x	Δ	x	o	x
[Illegible]	o	x	o	o	o
Portability	x	x	x	o	Δ
Cost	Δ	x	Δ	o	Δ
[Illegible]	x	Δ	Δ	o	o

A comparison of various displays by the methods mentioned above is shown in Table 1.

4. Outline of the Device

Explanations will be made regarding the following characteristics of this device. The main specifications are shown in Table 2.

(1) A high color rendering metal halide lamp was newly developed for reproducing the natural colors by liquid crystal, and high intensity, low electricity consumption, and long life were realized at the same time.

(2) A zoom lens was adopted to take full advantage of the compactness and lightweightness of the liquid crystal projector, and it was made so that anyone could easily set a large screen size of from 20 inches up to the maximum of 100 inches. Moreover, it has been made so that the picture size can be reduced to one-half without changing the projection distance.

(3) The monochromatic liquid crystal panel of the 3-inch TN-type TFT active matrix system was made of three-piece composition to secure color reproducibility and high resolution.

(4) After the white light of the metal halide lamp was divided by the dichroic mirror, it was incident upon the monochromatic liquid crystal three-piece composition, and a system combining the modulation light with the liquid crystal panel was generated.

(5) The 3-inch monochrome TFT liquid crystal has been newly developed for this device. It has a pixel composition of 382.5 H x 234 V and has been made a fine pixel composition amounting to a total of 268,515 pixels.

(6) Making parts more lightweight has made it possible for the liquid crystal to become lightweight. A weight of 13.8 kg has been achieved when including the zoom lens, and sufficient portability has been realized for practical use.

(7) The causes of image quality deterioration, in addition to S/N (signal to noise ratio), were pursued in relation to large screen sizes, and devices suitable for large-sizing were worked out.

5. Liquid Crystal (LCD) Panel

The 3-inch monochrome TN system TFT active matrix LCD panels newly developed for projection are used in this equipment. First, a brief view of the operating principle of the TN system that serves as the basis of display is shown (Figure 1). This rotates the polarized light, but, when an electric field is applied, capacity to rotate the polarized light is lost. Therefore, the transmitted quantity of light can be controlled according to the presence of an electric field by providing a polarizing plate on both the light input and light output sides.

Table 2. Main Specifications of Liquid Crystal Projection Display

Type name		XV-100Z
Display method		Three liquid crystal panels, three primary color optical shutter system
Liquid crystal panel	Panel size	Type 3 (vertical 4.5 cm, horizontal 6.2 cm)
	Display method	Transmission type TN liquid crystal panel
	Drive method	TFT (thin-film transistor) Active matrix drive system
	No. of color pixels	89,505 color pixels (vertical 234 x horizontal 382.5) x 3 (Equivalent to 268,515 color pixels)
Lens		Zoom lens F 4.5 f = 145~265 mm
Light source		Metal halide discharge lamp
Power source		AC 100 V (50/60 Hz)
Electricity consumption		220 W
Cabinet		Plastic
Connecting terminal		S image input terminal----- 1 system Video input terminal ----- 2 systems (image only) Monitor output terminal---- 1 system (image only)
Weight		13.8 kg
External dimensions		(W) 25.1 cm x (D) 58.5 cm x (H) 25.3 cm

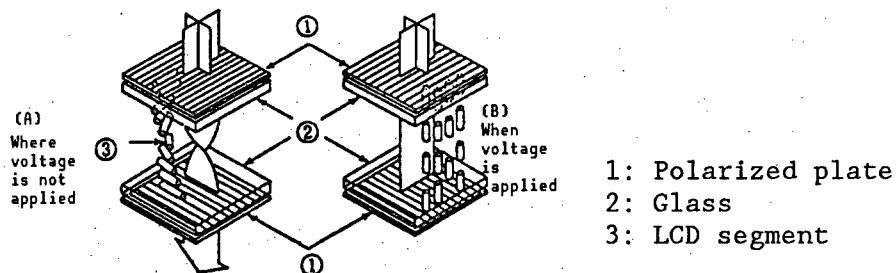


Figure 1. Operation Principle of TN System

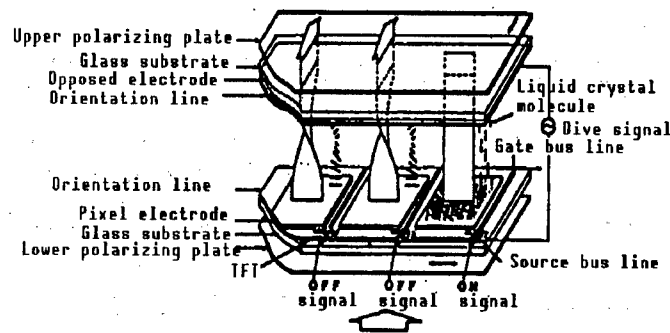


Figure 2. Block Diagram of Liquid Crystal Panel

The block diagram of the LCD panel is shown in Figure 2. TFT has been set so that it is connected in series with each pixel electrode at the intersection of the gate bus line and source bus line. Moreover, common electrodes (opposed electrodes) are formed all over against all pixels, with the liquid crystal layer in between. The a-Si TFT has been adopted as the LCD switching element. Each single line of the gate bus lines has been shifted in the horizontal direction by one-half pixel, and the pixels are configured in a delta shape.

It is necessary to provide a sufficient black display in order to obtain a high contrast in the normal white display system. Since the liquid crystal molecules change their direction perpendicularly to the electrode surface when voltage is applied between electrodes, the optical activity of the liquid crystal layer is lost and that part becomes dark. In this manner, a high voltage image signal is necessary to prepare a complete dark condition. The opposed electrode of the LCD panel is apparently reversed in the direction the image output is increased to compensate for this voltage. Moreover, the color filter periphery is of a black matrix structure to also improve contrast. An image with a high contrast of more than 100:1 is available due to these measures.

6. Optical System

The optical system is classified into the illumination system, which divides the light from the light source into RGB colors by the mirror and irradiates LCD, and the projection system, which projects the transmitted light from the LCD after combining it with the mirror by means of the projection lens. Such a division/combination system of light is called the mirror sequential arrangement system. There is another system that uses the dichroic mirror and prism jointly. In this prism system, the light coming from the light source, only the blue light is reflected by the first dichroic mirror, while the green light is reflected by the next dichroic mirror. Then, the red color remaining is reflected by the mirror. The light quantity of each light is controlled according to the video signal when passing the LCD panel, and images of red, green, and blue are prepared.

These three color images are combined into a single image by the dichroic prism and reproduced as a color image on the screen through the projection lens. When comparing these images, the former is comparatively large. However, this system has advantages such as ease of preparation during production, ease of adjustment, etc.

(1) Illumination System

The illumination system irradiates the respective LCDs by making the light coming out from the light source form a single color light. Since the LCD temperature rises in this case, the temperature rise of LCDs from the disuse energy of the irradiation light is controlled by eliminating the ultraviolet and infrared rays by the light source reflection plate, color mirror, and UV-IR cut filter, together with conducting forced ventilation with two fan motor units.

(2) Projection System

The light from B-LCD is reflected by a reflection mirror, but in the case of the R-LCD there is no reflection. Two reflections occur, however, for G-LCD. When left in this condition, the R, G, and B images become mirror images. Therefore, the left and right of the image on B-LCD is reversed with respect to the images on R-LCD and G-LCD.

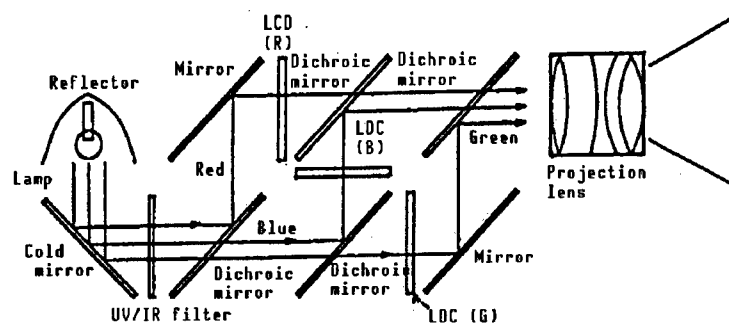


Figure 3. Mirror Sequential Arrangement System

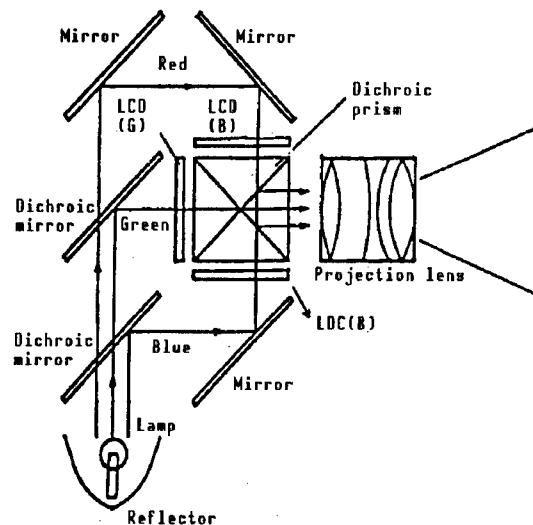


Figure 4. Prism System

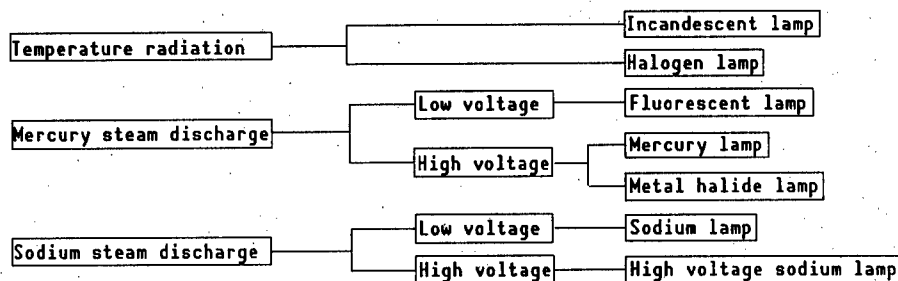


Figure 5. Classification by Light-Emitting Principles

A zoom lens is used for the projection lens, and the screen size varies in the range of from 20~100 inches.

- Projection lens

F 4.5

f = 145~265 mm zoom lens

7. Light Source (Newly developed light source)

Lamps generally put to practical use can largely be classified, as shown in Figure 5, according to the light-emitting principle. In particular, the mercury lamp, high voltage sodium lamp, and metal halide lamp are named generically and called "HID lamps."

One type uses the halogen lamp for the light source lamp, while another uses the metal halide lamp.

The color temperature of the halogen lamp is comparatively low (about 4,000 K) and its life is short (500 hours). In contrast to this, the color temperature of the metal halide lamp is high and the color is close to natural color and brightness. An efficiency of more than three times that of the halogen lamp has also been obtained.

(1) Metal Halide Lamp

The metal halide lamp adopted for the liquid crystal projector has a high light-emitting efficiency, the efficiency, color rendering, and luminous intensity change according to the metal halide combination and, since a continuous light is generated over the entire visible area, as shown in the relative spectral distribution of Figure 6, it is rich in color rendering, demonstrating a well-balanced emission spectrum appropriate for the liquid crystal projection-type projector.

(2) Stabilizer

The operations of the stabilizer that lights the metal halide lamp can be largely classified into two—discharge lamp starting and stability. The stabilizer not only affects the performance of the discharge lamp, but also exerts an effect on the circuit design.

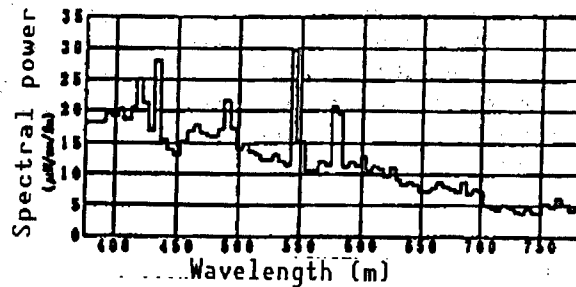


Figure 6. Relative Spectral Distribution Characteristic

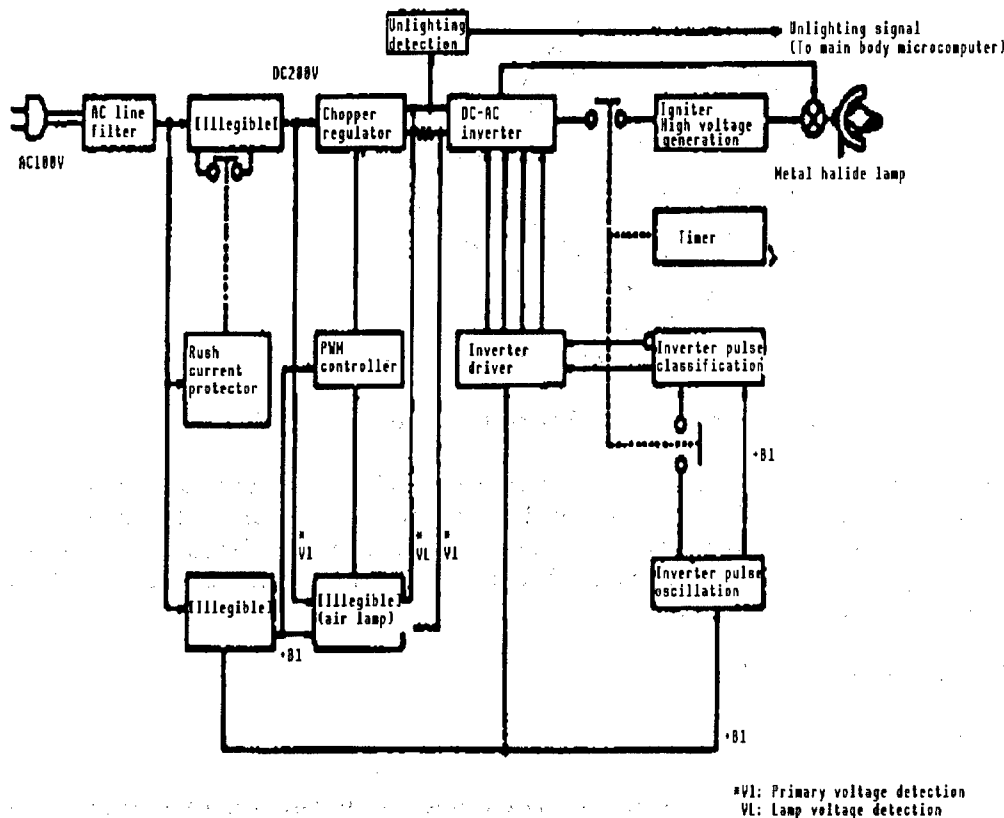


Figure 7. Block Diagram of Stabilizer

The lamp is thus started and stable light-emission occurs by maintaining a fixed voltage (150 V).

8. Color Reproducibility

The mirror sequential arrangement system in which dichroic mirrors are configured for wavelength selection has been adopted for the optical system to select single color wavelengths of red, green, and blue with high purity from the white color light projected by the metal halide lamp. The characteristic of this mirror is that specific wavelengths are reflected and other lights are passed by forming a multilayer film of dielectric substances with different

refractive indexes on the glass surface. Only the single color wavelength is left by utilizing this, and three color decomposition and three color combination are conducted. Moreover, the three primary colors are guided out by the configuration of the lamp, mirror, and condensing lens, and an adjustment to a finer color balance is made by setting the optical path system at an equal distance until combining occurs.

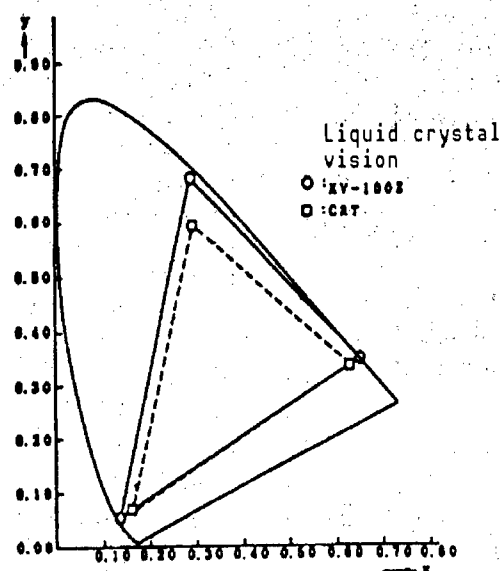


Figure 8. Color Reproduction Range

The color reproduction range of the liquid crystal projector shown in Figure 8 is compared with that of a color TV Braun tube according to the effects mentioned above and is shown on the CIE chromaticity diagram. The color reproduction range is wider than that of the Braun tube, and it is possible to reproduce a more natural color.

9. Signal Processing Circuit

(1) Chroma Signal

Color noises exist in various video sources due to video camera characteristics, deterioration from dubbing, rotary system jitter, etc., and it is extremely difficult to see. The color noise has been removed from its source and a two-dimensional color noise reduction (CNR) system that does not affect the high-quality image source that has been adopted in this equipment. The color signal noise reduction system is shown in Figure 9.

The chroma signal that has been Y/C divided by the comb-type filter is input to the cyclic type filter by the LH glass delay line, and the vertical direction noise is removed. However, the vertical resolution of the color will deteriorate when left in this condition. In order to correct this, the difference between the original signal and filtered signal is removed, the contour part only of the vertical direction is extracted by nonlinear processing of the signal, and this is also added to the output. With this, the noise area only is filtered by the vertical contour component in the preserved condition.

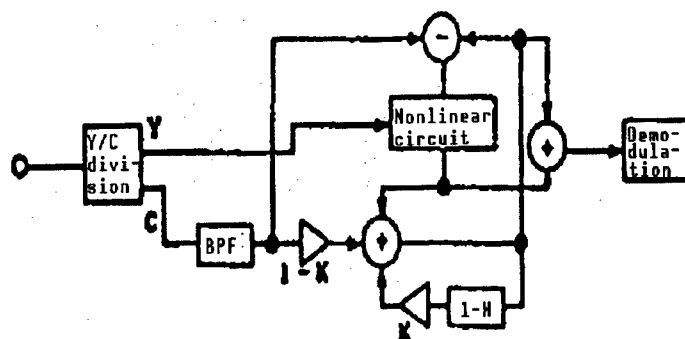


Figure 9. Color Signal Noise Reduction

(2) Luminous Intensity Signal

The luminous intensity (Y) signal noise reduction (YNR) system is shown in Figure 10. After having been image quality controlled, the divided luminous intensity signal is divided into the high-pass and low-pass components by the high-pass filter (HPF) and low-pass filter (LPF). The high-pass component is the noise reduction circuit (core ring circuit) that utilizes the forward direction characteristic of the diode and it reduces the noise component and corrects the contour. On the other hand, the low-pass component amplifies by means of the low-pass amplification circuit and obtains the luminous intensity signal of the noise-reduced high image quality by combining with the output of the high-pass amplification circuit.

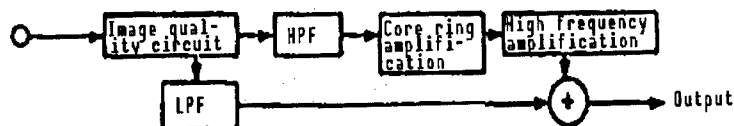


Figure 10. Luminous Intensity Signal Noise Reduction

10. Conclusion

We were able to develop a field differing from the Braun tube-induced direct-vision and projection-type displays by using a high density LCD panel excelling in light speed and heat resistance that was newly developed for projection, and the metal halide lamp which offers low electricity consumption, high intensity, and long life.

In the future, a high quality picture image display for use in such media is the enhanced definition and high-definition televisions is expected by tackling the further densification of the LCD panel and realizing the higher luminous intensity of the lamp.

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Liquid Crystal Light Valves, Applications

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[Article by Sadayoshi Hotta, Audio Video Research Center, Display Technology Research Laboratory, Matsushita Electric Industrial Co., Ltd.]

[Text] 1. Introduction

With the new information society, the demand for displays to serve as man machine interfaces has become strong in both quantity and quality. Especially, the demand for large screens, high image quality, and large capacity is high amid the introduction of enhanced definition televisions (EDTVs) and high-definition televisions (HDTVs).^{1,2} The projection-type display is entertained as potential technology for realizing these demands due to the following points.³⁻⁶

- (1) A compact and lightweight display can be realized.
- (2) The light source and picture processing section are separate, and high resolution and clear picture information are available.
- (3) The color reproduction range is wider than that of the conventional CRT.

The projection-type liquid crystal display consists of the following four basic components: 1) the light source, 2) the light valve, 3) the optical system, and 4) the screen. In this article, reports will focus on item 2) the light valve and its application.

2. What is the Light Valve?^{7,8}

The light valve (LV) literally is the general term for something which modulates light, and is also called the spatial light modulator (SLM). It is a component whose optical properties change with real time according to the various optical and electrical input signals, and which modulates the uniformly irradiated light to one-dimensional or two-dimensional optical information according to the input signal.

All non-light-emitting-type liquid crystal displays on which modulated light can be observed directly with the naked eye can be used as light valves.

However, the demanded performance differs and the developed component also differs with the application. The light valve has been developed as a projection-type large-screen display. The comparative object for the component performance is the film used for projectors and photos, and a film that does not require developing and for which real time processing is possible may be one of the targets. It goes without saying that the competitive rival in picture display performance is the CRT. Moreover, its importance has been increasing recently in the optical information processing field of incoherent and coherent conversions, etc., as well, and applied R&D to real time correlation operation and optical computing is also being promoted. In addition, the application of the electronic shutter and its adoption as one-dimensional array for the optical printer, etc., are also being actively studied. Examples of light valve applications can be listed as follows:

(1) Projection-type displays

- a. Video projector⁹
- b. Projection type TV¹⁰⁻¹²
- c. Stereoscopic television¹³
- d. Overhead projector (OHP)¹⁴
- e. Head-up display (HUD)¹⁵

(2) Printer¹⁶⁻¹⁸

(3) Optical information processing

- a. Analog operation such as correlation operation, etc., of images¹⁹
- b. Hologram record²⁰⁻²¹
- c. Optical computing²²

The liquid crystal light valve will be compared to various other light valves and, in particular, a detailed report will be made on the projection-type display for which the application development is thriving and which also demonstrates high performance as a liquid crystal light valve.

3. Classification of Light Valves (see Table 1)

Light valves (spatial light modulators) that have been classified according to 1) signal input method, 2) light modulating medium (element composition), and 3) light modulation system (output system) are listed in Table 1.³

The input method can be largely classified into 1) input by electron beam scanning, 2) light input, 3) input by thermal write, and 4) input by electric signal input to matrix electrode.

The output method can be classified into 1) output by utilizing the phase difference according to the unevenness, etc., of the surface (the method of generating a minute unevenness on a thin oil film formed a concave mirror by an electron beam, obtaining an optical phase difference and outputting the light and dark images by the Schlieren optical system corresponds to this); 2) output as the light intensity by utilizing the polarization plane rotation and combining the polarizer and analyzer; and 3) output as the change of the

Table 1. Classification of Light Valves

Image information source (signal input method)	Optical modulation medium (spatial modulator)	Optical modulation method	Remarks
Electronic beam	Fluorescent substance Oil film	Emission Diffraction	Idohol (GE Co.)
Laser beam (visible)	Nil Photoconductor/LC BiSiO	Direct drawing Polarization Polarization	Sumitomo Electric Industries Hamamatsu Photonics Co.
(IR)	Photocathode/LiMbO (MCP) Smectic LC	Polarization Scattering	Hitachi, Ltd. Nippon Electric Sony Corp. Seiko Electronics
CRT	Photoconductor/LC	Polarization Polarization	Hughes Co.
Electric (simple matrix)	Smectic LC Ferroelectric LC STN (white mode) PZT	Scattering Polarization Polarization Polarization	Matsushita Electric Industrial
Electric (active matrix)	MIM LCD TFT LCD	Polarization Polarization	This report, Sharp Corp., Seiko Epson Co., Ltd.

transmitting or reflecting light intensity by changing the scattering degree. The performances of various light valves are compared and listed in Table 2. The film is not called a light valve, but it has been listed for comparison of performances.

4. Various Applications (Tables 1, 2)^{23,24}

Light-light conversion has become the mainstream in recent optical computing and optical operation processing, and many spatial light modulators of optical input are used. Many reports have been made on examples using the 1) electro-optical crystal $\text{Bi}_{12}\text{SiO}_{20}$ (BSO)²⁵ which exhibits photoconductivity, 2) type which charge stores the photoelectrons from the photocathode on the electro-optical crystal (LiNbO_3) surface via the microchannel electron multiplier plate

Table 2. Performance of Various Light Waves

Type of element	Element composition	Write voltage (V)/ Energy (mJ/cm ²)	Contrast	Resolution (lp/m)	Write time (mS)	Remarks
Film Oil film	AgBr Electron beam	Electric current: 20 μ A	10,000 ≥ 140	1,500 32	— 1~10	Developing time GRETAG (Idohol) GE
BSO MCP	Bi ₁₂ SiO ₂₅ Photo-cathode LiNbO ₂	1k/ 2.5x10 ⁻³ 1k/ 2.2x10 ⁻⁴	5,000 1,000	≥ 100 10~20	10 ⁻³ 100	Hamamatsu Photonic (MSLM)
Thermal write LCD Optical write LCD	IR/laser Smectic CdS/TN a-Si/FLC	20/0.1 20/2.4x10 ⁻³ 20	15~30 ≥ 100 1,000	≥ 100 35~100 100	30,000 30 0.4	Vector scanning (CAD, CAM) CRT input (LCLV)
Elec- tric write	CCD/Tn Simple/	—	50	32	30	Super Homeotropic Super TN N-Ch phase transition Two-dimensional One-dimensional Polymer dispersed LC
	SH	10	30	10~30	50	
	STN	10	20	10~30	100	
	NCPT	15		10~30	2500	
	FLC	20	20	10~30	500	
	FLC	20	4~10	10~30	0.1	
	Active/ TN	10	≥ 100	10~30	30	
	PDLC	20	20~50	10~30	10~30	

(MCP),²⁶ and 3) type which uses the liquid crystal light valve (LCLV)^{27,28} combining photoconductors, such as CdS, a-Si, etc., and liquid crystal. (Although it is not known why, there are many cases in which this type is indicated when referring to liquid crystal light valves (LCLVs).) The optical white energy in Table 2 becomes one of the performance indexes in these applications.

An electric input is used for the printer application, and such properties as 1) response characteristics, 2) light-shielding property, and 3) memory characteristics are important. We have come across many reports recently that use ferroelectric liquid crystal (FLC) to satisfy these demands.^{17,18} This is

because the liquid crystal response characteristic of FLC is several μsec and is superior to the 30 msec of the conventional TN and GH. This good response characteristic of the ferroelectric liquid crystal has been noticed in recent years, and many examples applying it to the optical write LCLV are seen.²⁹⁻³¹

Moreover, liquid crystal light valves are used to conduct laser optical modulation to hologram records, optical processing, etc. The light handled in this case is of a single wavelength and, although it is not necessary to consider the effect of optical activity wavelength dispersion (optical rotary dispersion), as will be mentioned later, one will face interference and speckle noises due to the various interfaces of the element since it is a coherent light.²¹

Oil film-type light valves are old as application light valves and have been put to practical use as projection type displays of high resolution.²² These light valves are represented by the three tube system reflection type-Idohol, made by Gretag Co., Switzerland, and the two tube system transmission type Kuaria. They are extremely bright, but are intended for business use, rather than residential use, due to size, electricity consumption, and cost.

The systems using liquid crystal as the light valve began in the 1970s. They include Hughes Co.'s optical write type (1970)²⁷ and Kyoto University's thermal write type (1972).³³ Both of these systems have already been put to practical use. In particular, those of the thermal write type have been developed as displays for CAD and CAM by taking full advantage of such characteristics as: 1) miniaturization of device is possible by utilizing the laser semiconductor; 2) coloring is possible by the three plate system; 3) the polarizing plate is not necessary and is clear since light scattering can be used; and 4) the resolution is high.³⁴ On the other hand, both types are large and complicated, and it is expected that they will prove difficult to use for general purposes in the private sector. In addition, the thermal write type is quite slow and is not appropriate for video rate application.

On the other hand, the practical application to overhead projectors (OHPs) and head-up displays (HUPs) is also active with the enlargement and large capacity realization of the dot matrix type liquid crystal panel. The progress of the liquid crystal panel is actually the progress of the light valve, and various application developments are being promoted. Specifically, it can be said that it has become possible to put the OHP application to general use owing to the fact that a comparatively high contrast large panel can be supplied at low cost by the development of new display modes, such as the liquid crystals super twisted-nematic (STN) mode³⁵ and super homeotropic (SH) mode.³⁶ The picture plane write is 2.5 seconds and long for those using the nematic-cholesteric phase transfer type liquid crystal, but the polarizing plate is unnecessary and is clear. OHP applications with characteristics such as the capability of four color display without a color filter by the two-layered panel, etc., have also been reported.¹⁴

A multicolor projection-type display for CAD and CAM possessing a high resolution of 2000 x 2000 by using a ferroelectric liquid crystal with a memory property and good response characteristics was reported recently.⁵⁵ The rewrite time is 0.5 second. A display capacity with a density that compares favorably

with that of the thermal write projection type display mentioned above is formed into a compact display with a simple system composition and comparatively fast write time.

In Table 1, those using the Braun tube (CRT) were the mainstream as image information sources for full color image applications such as televisions, etc., in which the rewrite speed of the video rate and high image qualities (contrast, gradation, color reproduction, high responsibility, etc.) were demanded. Recently there has been flourishing research to apply to projection-type television's active matrix type liquid crystal panels (thin film transistor drive liquid crystal display: TFT-LCD, etc.), whose high image quality continues to be demonstrated through applications to liquid crystal pocket televisions, with some reaching the commercialization stage.⁹⁻¹¹ Since it is possible to realize a bright large capacity picture, free from deterioration of resolution, by tackling the high luminous intensity realization of the light source, it is attracting attention as a technology with the highest possibility of realizing a high-definition television for home use.^{1,2}

Compared to the simple matrix type, the active matrix type liquid crystal panel has good image performance, but the cost is comparatively high due to the complexity of the production process.

More detailed explanations will be given regarding the application to high performance projection type televisions, as well as the active matrix liquid crystal light valve that is used for the application.

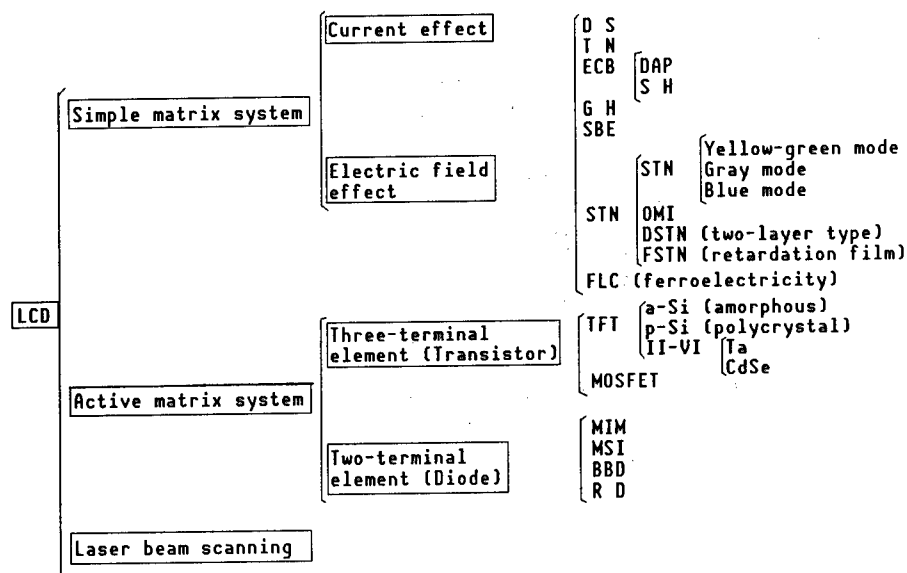
5. Active Matrix Type Liquid Crystal Light Valves and Their Projection Type Applications

5.1 What Is the Active Matrix Type Liquid Crystal Light Valve?

The active matrix type liquid crystal light valve is a device where nonlinear elements, such as the thin film transistor (TFT), metal, insulating material, and metal varistor (MIM), etc., are formed as switching elements in each pixel, and has been designed so that a high performance display can be drawn out by the static driving of the liquid crystal.

As shown in Table 3, active matrix type liquid crystal light valves can be classified by the type and material of the nonlinear elements used. Moreover, as shown in Table 2, they can also be classified by the operation mode of the liquid crystal. In the former classification, TFT consisting of amorphous silicon (a-Si) or polysilicon (p-Si) and MIM represent the current mainstream of practical application and R&D. In the latter classification, those using the TN liquid crystal have been put to practical use in televisions, and most studies involve these. However, those using the ferroelectric liquid crystal and those using the polymer dispensed liquid crystal (PDLC) as a liquid crystal impregnated in a sponge-like polymer thin film have been reported recently.⁵⁶⁻⁵⁹

Table 3. Classification of Liquid Crystal Valves



Those using PDLC have the following characteristics and represent a promising technology.

- 1) The housing process of the liquid crystal is extremely simple.
- 2) A high transmission rate is obtained without the need for a polarized plate.
- 3) Large screen is possible.

Those with operating voltages of 10~20 V and contrast 50 are available according to the recent report.

The active matrix type TN liquid crystals excel in such image performance as contrast, response characteristics, etc., when compared with the simple matrix, and their performances compare favorably with the image qualities of the Braun tube (CRT).

However, although the process involving building in the switching elements with a good yield represents a major topic, this process is slightly complicated and the cost is high in comparison to that of the simple matrix drive. In particular, the yield drops precipitately when the large capacity and defect-free one, like that demanded for the projection-type application, is realized. Therefore, the following countermeasures are being studied.

- 1) Simplification of production process.³⁷
- 2) Introduction of redundancy design.³⁸
- 3) Multilayering of insulating film between layers.³⁹

The development elements of the liquid crystal light valve are presented in Table 4.

Table 4. Development Elements of Liquid Crystal Light Valves in Projection Type Applications

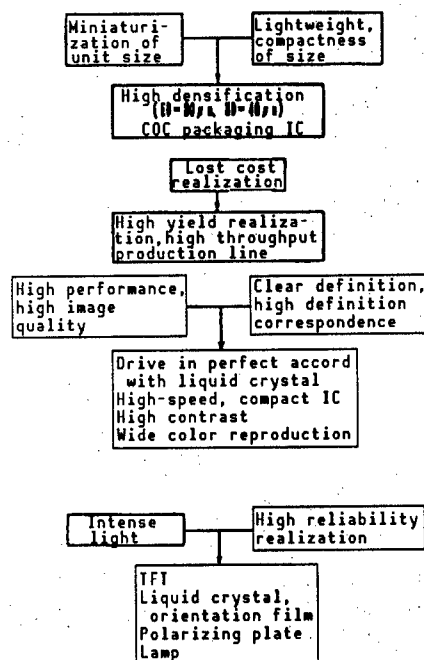


Table 5. Development Status of Liquid Crystal Projection Type Displays

Item	Matsushita Electric Industrial Co., Ltd.	Matsushita Electric Industrial Co., Ltd.	Sharp Corp.	Seiko Co., Ltd.
Form	One-body type rear		Two-body type front	
Liquid crystal panel	2.3°	2.8°	3°	1.27°
No. of pixels	1.36 million x 3	312,000 x 3	99,000 x 3	70,000 x 3
Horizontal resolution	1,100 TV lines	500 TV lines	290 TV lines	230 TV lines
Optical system	Mirror/ 3 lenses	Mirror/ 3 lenses	Mirror/ 1 lens	Prism/ 1 lens
Lamp	Metal halide 250 W	Metal halide 250 W	Metal halide 150 W	Halogen 300 W
Weight	50 kg	45 kg	13.8 kg	7.3 kg
TFT	a-Si	a-Si	a-Si	p-Si
Display mode	NB (HFE)	HB (DTN)	NW	NB (CEM)

5.2 Recent Development Condition of Projection Type Applications

In Table 5, we examine the developmental status of liquid crystal projection televisions using the TFT LCD of various companies such as Matsushita, Seiko, and Sharp. All the companies except for Matsushita have adopted a two-body-type front system projector application to replace the conventional projector. Such companies as Seiko and Sharp have emphasized the point that low cost is feasible, although the picture may be rough, by using a liquid crystal panel of 70,000~90,000 pixels which has been applied to pocket televisions, etc.

Moreover, as shown in Table 5, all these companies have adopted amorphous silicon (a-Si)⁴²⁻⁴³ as the TFT except for Seiko, which has adopted polycrystal silicon (p-Si).^{40,41} The advantages and disadvantages of p-Si and a-Si are compared and examined Table 6.

Table 6. Comparison of a-Si TFT and p-Si TFT

	a-Si TFT	p-Si TFT
Advantages	• Low cost glass substrate • Production established by large-area substrate (Advantageous for cost reduction)	• Drive incorporation possible (Packaging simple, advantageous for miniaturization) • Production process established by small-area substrate (Diversion of semiconductor equipment possible) • Advantageous for color fastness and heat resistance
Disadvantages	• Cost of packaging process is high	• Process long for driver fabrication • Substrate cost is high • Difficulty in enlarging

Since p-Si, which is capable of incorporating the peripheral driver, can miniaturize the LCD module comparatively easily, it is extremely advantageous for the miniaturization of the system. Moreover, p-Si is also advantageous regarding heat resistance, light resistance, drive reliability, etc., but the question will be whether the high-speed peripheral driver that copes with high definition can be incorporated with a good yield. In comparison, the advantages of a-Si are that a low cost glass substrate can be used since fabrication is possible for a comparatively low process temperature, and cost reduction is possible by batch manufacturing many panels from large area substrates. Therefore, the following become the topics involving a-Si TFT, for which incorporating a built-in driver is difficult.

- 1) Miniaturization of driver IC.
- 2) Compact IC packaging (For example, chip-on-glass packaging method which mounts IC directly on glass,⁴⁴ COG, etc.).
- 3) Reduction of packaging cost.

5.3 Application Forms

Two types (transmission type⁹⁻¹¹ and reflection type^{12,45}) of active matrix type liquid crystal light valves can be considered. The type theoretical diagram of these optical systems⁴⁸⁻⁴⁹ is shown in Figure 1(a) and (b). In contrast to the transmission type which uses a polarizing plate, the reflection type uses a polarizing beam splitter. In Figure 2(c), the size and weight of the system when the projection-type display with a display screen of 40 inches was trial manufactured by using a light valve from a 3-inch diagonal screen is compared with the projection type television using the direct-vision type CRT in Figure 2(a) and the CRT of Figure 2(b) with a display screen of about the same size. It will be understood that a compact and lightweight display previously not available can be realized.

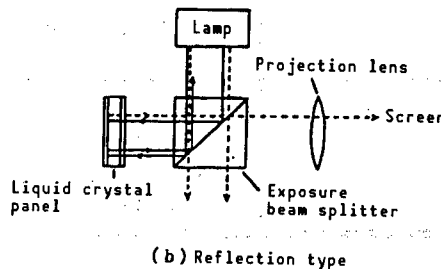
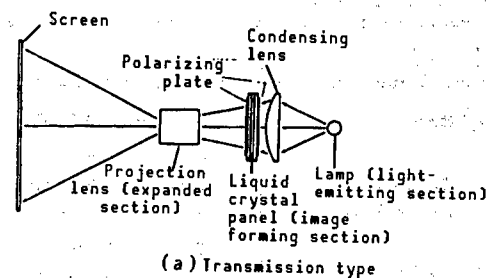


Figure 1. Type Theoretical Diagram of Projection Optical System

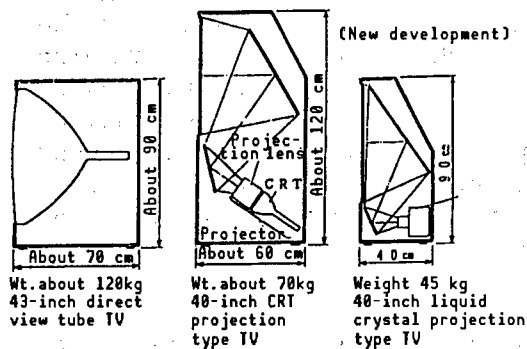


Figure 2. Comparison of Displays

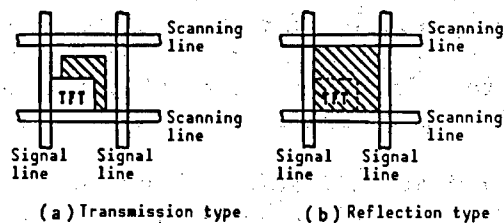


Figure 3. Comparison of TFT Array Numerical Apertures

Active matrix-type liquid crystal light valves that possess a thin-film transistor (TFT) in each pixel have the numerical aperture of pixels impeded by TFT, as shown in Figure 3(a), and transmittance is reduced. The relationship between the numerical aperture and resolution of TFT-LCD reported up to now is shown in Figure 4. It is shown by dividing it into a-Si TFT (o) and p-Si TFT ($\square$). Although it had conventionally been said that p-Si TFT was advantageous for high resolution, both have numerical apertures of around 50 percent for the resolution in the neighborhood of 13 lines/mm, and there is not significant difference when a high contrast is demanded in the projection type application as shown by the said drawing. Moreover, the numerical aperture declines precipitately when it becomes of high density. The reflection type is expected to resolve these problems. It is intended to reduce the numerical aperture drop caused by TFT and obtain a high modulated quantity of light by forming a reflection electrode on TFT, as shown in Figure 2(b). The resolution is about 30 lines/mm for the HDTV correspondence (1.2 million pixels) in Table 5, but a result exceeding 60 percent has been obtained for the numerical aperture.¹² (As shown in Figure 4, the numerical aperture drops precipitately near the resolution of 30 lines/mm for the transmission type.)

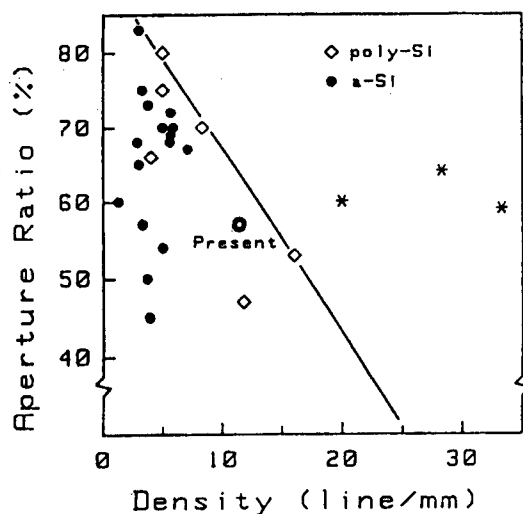


Figure 4. Relationship Between Numerical Aperture and Resolution of TFT-LCD

5.4 Display Performances

5.4.1 Light Fastness

The photoconductivity of p-si is comparatively small and a sufficient display performance is available during ordinary application without light shielding. On the other hand, while a-Si has extremely good photosensitivity, as can be seen from the fact that it is used for the solar cell and optical sensor, this has become a big disadvantage when used as a TFT. The photocurrent has been reduced by making the a-Si layer less than about 50 nm thick, and the optical deterioration of the TFT switch-off resistance has been controlled to counteract this disadvantage and maintain the image quality under strong incident light as well.^{42,43}

5.4.2 Heat Resistance

Since the panel temperature rises with the strong incident light, the LCD used for projection application must maintain stable performance at high temperatures. Figure 5 shows the LCD temperature dependence of the input signal (V_{50}) and contrast ratio. As a result of an overall optimization of a-Si TFT LCD (1) TFT itself, 2) orientation film, 3) temperature, etc.) a contrast ratio of more than 100:1 has been secured in the LCD temperature range of 20~50°C, and the change in V_{50} has also been kept less than 0.3 V.

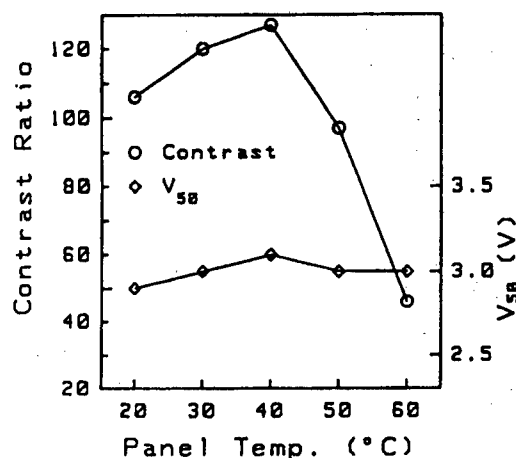


Figure 5. LCD Temperature Dependence of Input Signal (V_{50}) and Contrast

5.5.3 Color Reproducibility

A superior color reproducibility is an extremely important factor in high image quality display. There are two types of display modes—the negative mode (normal black, NB) and positive mode (normal white, NW) of the twisted nematic (TN) liquid crystal. Both modes have advantages and disadvantages, as shown in Table 7.

The positive display has a comparatively natural color change and color reproduction is easy, however, since the numerical aperture and photoabsorbance become low in applications demanding a high contrast, it is considered disadvantageous for high densification. As shown in Table 5, Sharp Corp. has adopted a positive type and boasts an extremely good display performance of black.

On the other hand, it is believed that a negative display is advantageous for obtaining a high numerical aperture for the LCD. However, it becomes important to compensate for the optical rotary dispersion peculiar to the TN liquid crystal in this case to obtain superior color reproducibility.⁴⁹ Since each light spectrum of RGB used as the projection light source is broad in comparison to that of the three waveform type fluorescent light power source of a pocket television, it can be said that the compensation for optical rotary dispersion in TN-LCD used for the projection-type television will be more difficult than it will for the pocket television.

Table 7. Comparison of Negative and Positive Displays

	Negative display	Positive display
Advantages	• Comparatively low voltage drive • Light incident angle dependence comparatively wide • Wide numerical aperture design easy	• Contrast is great when light-shielding is sufficient • Nonorientation parts, such as bends, etc., are not conspicuous • Color change is comparatively natural
Disadvantages	• Spacer is conspicuous • Coloring measure of black necessary • Color change by optical rotary dispersion is great	• Drive voltage is comparatively large • Light incident angle dependence is great • Numerical aperture drops due to light shielding

All companies are conducting various studies regarding compensating for this optical rotary dispersion. As shown in Table 5, Matsushita Electric Industrial Co., Ltd., has adopted a DTN structure (two-layered TN structure in which a compensating plate consisting of a liquid crystal panel is placed on the light incident side of TFT LCD). This technology is the same as that used for the two-layered system STN, with the exception that the twisted angle is 90° .⁵⁰ The relative transmittance of the black level against the white level was less than 1 percent along the wide wavelength range (400~700 nm) by employing the DTN structure and, therefore, a contrast ratio of more than 100:1 was available for the entire RGB wavelength range.

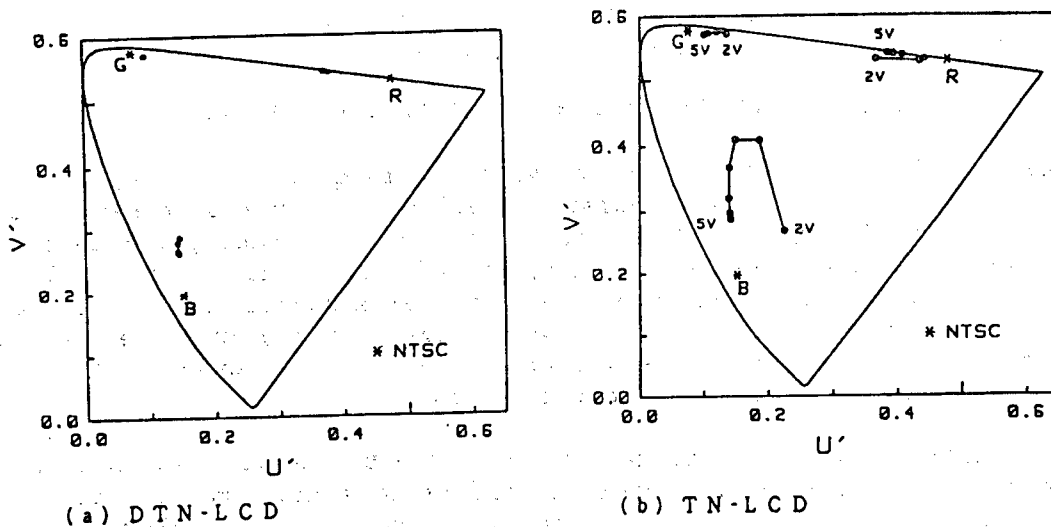


Figure 6. Signal Voltage Dependence of RGB Color Coordinates

The chromaticity change when conducting gradation display (when inputting various signal voltages to LCD) in the DTN structure (a) and single layer TN structure (b) is shown in Figure 6 by a chromaticity diagram. As shown in the diagram, the available chromaticity of TN-LCD changes substantially against the signal voltage change from the black level to the white level, however, it does not change to a practical degree in DTN-LCD. This indicates that gradation can be reproduced without changing the chromaticity. The same effect can also be expected in a composition using a $\lambda/4$ plate (phase compensating film) in place of this DTN structure.^{51,52} The transmittance-signal voltage (T-V) characteristic of TFT LCD by the DTN structure under each RGB light source is shown in Figure 7. Despite the fact that a TFT-LCD of absolutely the same liquid crystal material and liquid crystal thickness is used, a black level of less than 1 percent (more than the contrast ratio of 100:1) has been achieved under all RGB light sources. Moreover, it demonstrates that it is able to drive by practically the same pedestal voltage level in each RGB. In other words, it is not necessary to prepare the comparatively high cost TFT LCD according to different specifications for each RGB, and it can be said that TFT LCD adopting the DTN structure is a technology excelling in mass productivity.

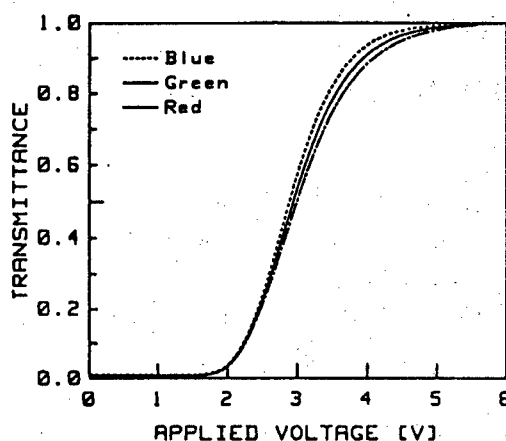


Figure 7. RGB Dependence of T-V Characteristic

Furthermore, Seiko Co., Ltd., has coped with the range that is comparatively insensitive to optical rotary dispersion, called the contrast enhanced mode ($\Delta n \cdot d / \lambda = 2.4 \sim 2.5$ of Figure 8, here, Δn = birefringence ratio, d = thickness of liquid crystal, λ = light wavelength) by selecting the Δn of the liquid crystal for each of the three primary colors.^{53,54} As a result, the chromaticity change according to the signal voltage for the chromaticity ordinates and each RGB wavelength dependence of the T-V characteristic has been controlled to a low level, similarly as was achieved for the DTN.

The chromaticity reproduction range obtained from the above results is shown in Figure 9. As a result of the superior performances and light source of TFT LCD and the optimum designing of the dichroic mirror, etc., a color reproduction range exceeding that of the CRT has been obtained, as is clear from Figure 9.

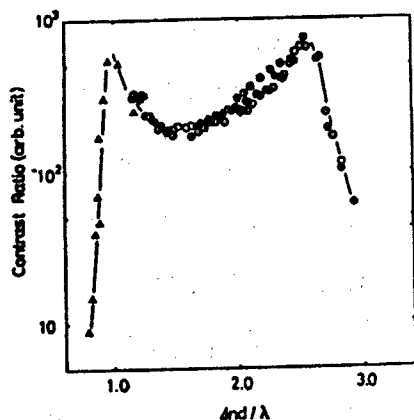


Figure 8. $\Delta n \cdot d / \lambda$ Dependence of Contrast

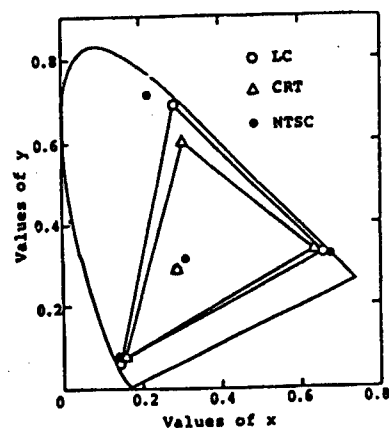


Figure 9. CIE Chromaticity Diagram

6. Conclusion

It can be considered that all the theoretical and applied light valve devices have already made their appearance, however, certain performances are demanded for each applied device and the road to practical use depends a great deal upon future R&D. The problem lies in finding one that has a suitable price, size, and reliability, and is not of high resolution.

Aside from the problems of practical application, liquid crystal light valves have reached the stage of wide-ranging practical application. It gives us pleasure that various applied devices are coming to be realized with this.

Increasing speed with the development of ferroelectric liquid crystal will be important in the application of optical theoretical elements and printers.^{17,18} High reliability and high densification are the priority topics in projection-type applications,^{11,12,55} and high transmittance realization with the development of liquid crystals not using a polarizing plate, etc., are desired.^{14,56-59}

It is believed that the day is near when a display able to cope with a large screen high resolution, high luminous intensity and ultra-compact high definition display will be realized by the further development of active matrix type liquid crystal light valves and the improvement of the lamp/optical system.

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Large-Screen Liquid Crystal Matrix Display (Direct-View-Type)

906C0054G Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 63-70

[Article by Koichiro Kurahashi, Himeji-Dokkyo University]

[Text] 1. Introduction¹

It is thought that one of the purposes of the image information system lies in providing "vicarious experiences" of the world to man through the display screen, and a large-screen display allows imaging of the ultimate state. In other words, a system which provides a large-screen display as the terminal has the potential of realizing an ultimate information environment by completely filling up the visual (aural) space of viewers with a screen. Movies have created such an image space from old and highly detailed movies, as well as three-dimensional movies, by employing huge screens, and entire sky screens are suitable examples. The pseudo field of vision of a simulator, media room, etc., exist in the world of electronic images. Moreover, highly detailed televisions, as represented by the high-definition television, also point toward this direction. In addition, large-screen displays are also appealing as a media capable of offering common messages to multiple viewers amid the mutual direct contact of viewers and providing a response.

The applications of large-screen displays can largely be classified as follows and as shown in Figure 1.

(1) Large-screen televisions for homes and theaters are intended to present highly detailed images, adopting new dimensions, such as presence and immersion, by making the angle of view large, etc.

(2) In an information/control system or simulator, attempts to realize a visual interface make it possible to provide a multiplicity of information to numerous people simultaneously. A large screen becomes necessary to secure an information content which viewers can recognize, as well as to increase the displayed information content.

(3) In order to provide data messages to a vast number of people in indoor and outdoor arenas, sports complexes, or in towns, etc., by means of writing or images, information media which should be termed "open space media," are being realized. This employs a large screen so that the displayed information can be recognized even at long distances.

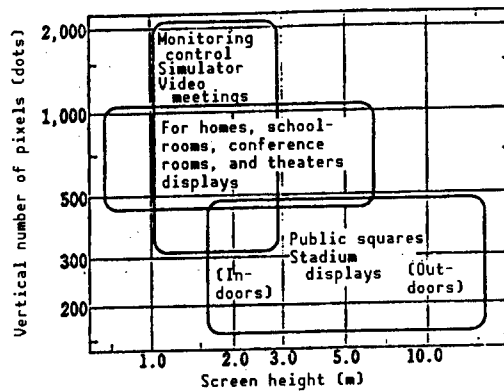


Figure 1. Applications of Large-Screen Displays

These large-screen displays consist of the projection and direct view types.

The projection type optically expands and projects the CRT screen and images formed by light valves, such as liquid crystals, etc., on the screen, and it is easy to realize a high resolution display. On the other hand, luminous intensity becomes insufficient when exceeding 100 inches since there is an upper limit to the beam, so it is appropriate for applications with controlled illumination and where a projection space can be adopted "closed space," such as in homes, theaters, etc.

The direct view type views the image on the surface plane of the display element directly, and in those in which the diagonal length of the screen exceeds 1 meter, modules of the light-emitting type display elements are arrayed and the system for obtaining the necessary screen size is utilized. Since the luminous intensity can be fixed regardless of the screen size, display with a good contrast is available even in bright peripheral conditions. Moreover, since a special space is not necessary in front of the display plane, it can be used in the "open space" of indoor and outdoor vacant lots. With this system, those that employ matrix-arrayed CRTs and fluorescent discharge tubes as pixels have been put to practical use as huge screen displays having a diagonal length of more than several meters.^{2,3,4}

Currently, displays in indoor open space, which is represented by underground shopping centers, airports and railway station concourses, etc., have a screen size with a diagonal length of 2~5 meters, and the position (viewing distance) of display viewers is comparatively short, at only several meters. A display with a pixel pitch of less than several millimeters becomes necessary for realizing the necessary resolution in such cases as well, and for providing viewers with a continuous feeling of images.

The full color direct view type image display, which adopts the system of arraying liquid crystal panels, has been put to practical use as a display in line with these trends. An outline will be given of the display of this system.

In addition, the shortening of the pixel pitch has also been promoted in CRTs and fluorescent discharge tubes, with a pixel pitch of 15 mm realized for arrayed composite CRTs.^{2,3}

2. Display With Arrayed Display Panels

2.1 Panel Type Display Element as the Display Module

A display in which the panel type display element of a single letter or several letters and numerals has been made the module and then, with that, displaying it in a large screen as a single entity by arraying the necessary numbers of modules required for the screen, has often been used for monitoring panels, message boards, etc. This system has the advantages that the pixel pitch and letter size can be selected comparatively freely in the module, and that versatility is also great for the size and resolution of the entire screen. In addition, since the luminous intensity will have nothing to do with the number of pixels of the entire screen when a drive circuit is provided for each module and each module is driven in parallel, there is also the advantage that it can be made of a high luminous intensity, even in a large screen.

When limited to displays of letters and numerals, no inconvenience is experienced, even when something cannot be displayed (dead space) between letters and between display lines, so practically all flat plate type displays can be used. LEDs, PDPs, ELs, etc., are appropriate for the above application.

First, as the structural problem when developing this system for the display of general images, the pixel pitch in and between modules must be made uniform, as shown in Figure 2. This pixel pitch between modules determines the pixel pitch for the display. Moreover, the joint between modules must be inconspicuous.

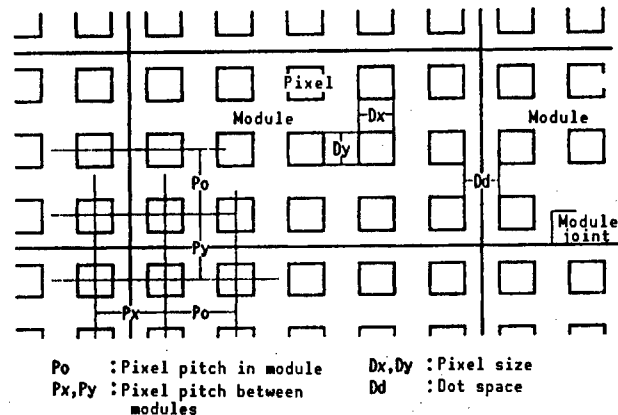


Figure 2. Concept of Module Arraying System

Since the dead space of the module peripheral edge parts of those arraying LED chips can be minimized, a pixel pitch of less than several millimeters can be realized. A message board has been put to practical use in this system,⁸ and there is the developmental example of two color (red and green) image display (pitch 2.54 mm, maximum 2.6 x 2.6 m²). However, since the efficiency of the blue light emitting diode is currently low, it is not appropriate for displaying color images.

2.2 Full Color Image Display by Liquid Crystal Panel

Since the panel peripheral edge (sealing and wiring leading part) can also be made comparatively small for the liquid crystal panel, a pixel pitch between modules of several millimeters can be realized without substantially sacrificing the numerical aperture.

Superior image characteristics can be expected by static driving the GH type liquid crystal. The following are the image characteristics:

- (1) Sufficient gradation control characteristic (driving voltage versus transmittance).
- (2) Large contrast ratio...for example, more than 60:1.
- (3) Superior visual field characteristic...for example, horizontal $\pm 60^\circ$.
- (4) Almost flat transmittance wavelength characteristic...coloring possible with color filters of three primary colors and a superior "black color."
- (5) Adaptability to screen size is improved by module realization, including backlight by means of a large beam.

The direct view type large-screen image display using the liquid crystal panel as the module has been developed and put to practical use by paying attention to these points.

3. Actual Examples of Direct-View-Type Liquid Crystal Large-Screen Displays

3.1 Example 1 (Spectus: Mitsubishi Electric Corp.)^{8,9,10,11}

A full color image display with a screen size equivalent to 90~200 inches has been commercialized. The system composition of the device is shown in Figure 10. It has a character-graphic system utilizing a personal computer, in addition to the audiovideo (AV) system, for functioning sufficiently as an image information media.

The display part is of a short viewing distance type with a pixel (primary color trio) pitch of 7.2 mm and is characterized by high luminous density (300 cd/m^2), high contrast (60:1), and uniform screen (free from unevenness of luminous intensity and chromaticity, and with an inconspicuous module joint).

3.1.1 Liquid Crystal Panel

A GH liquid crystal with a large contrast ratio and superior black chromaticity at light interception is driven statically. The drive voltage versus the transmittance, the angle of visibility, dependence of contrast, and response characteristics are shown, respectively, in Figures 3, 4, and 5. As seen here, the GH liquid crystal adapts sufficiently to image display. The panel characteristic is shown in Table 1.

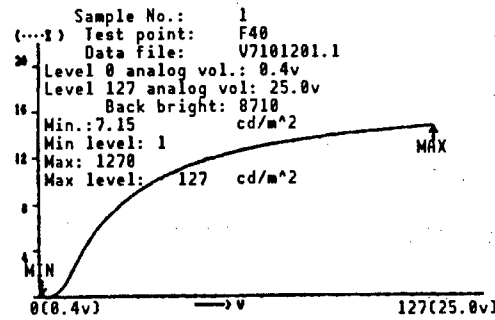


Figure 3. Voltage Vs. Transmittance Characteristic

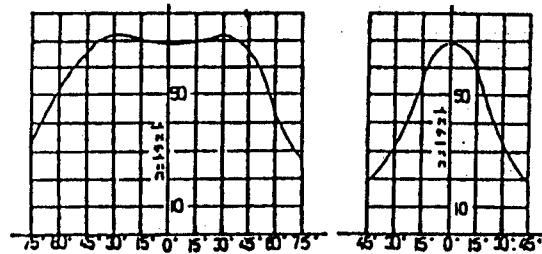


Figure 4. Angle of Visibility Vs. Contrast

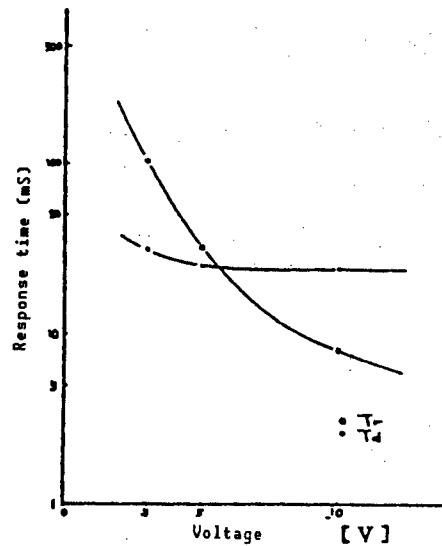


Figure 5. Response Characteristic

Table 1. Characteristics of Liquid Crystal Panel

Liquid crystal		Type GH
Panel size (mm)		230.4 x 86.4
Number of pixels		32 x 12 x 3
Pixel pitch		7.2
Response speed		Tr (ms) 25
		Tf (ms) 35
Angle of visibility	Up and down (degree)	±30
	Left and right (degree)	±60

3.1.2 Display Module (Liquid Crystal Unit)

The display module structure is shown in Figure 6. It is a box type that has improved the utilization factor of light and made the visual angle dependence smaller by providing a mirror treatment in the inner surface, and is a structure that maintains the other parts of the liquid crystal panel.

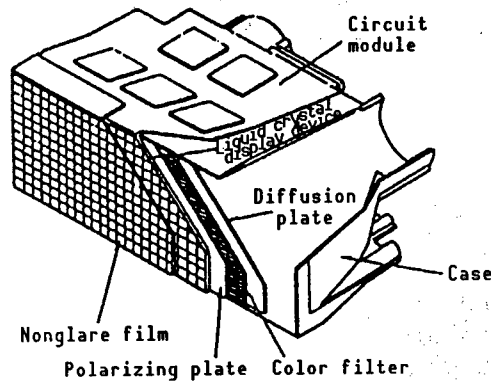


Figure 6. Structure of Liquid Crystal Unit

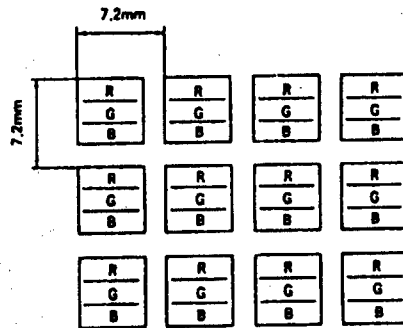


Figure 7. Arrangement of Pixels

The display module consists of the diffusion plate for maintaining the uniformity of luminous intensity, on glare film for preventing surface reflections, and a circuit module for driving the liquid crystal.

The layout of the three primary color pixels by the color filter, as shown in Figure 7, has the three pixels of RGB put together in a square array at the pitch of 7.5 mm. The color shifting by the angle of visibility in the horizontal direction is eliminated by dividing the color filter in the vertical direction.

The reproduction chromaticity range is shown in Figure 8.

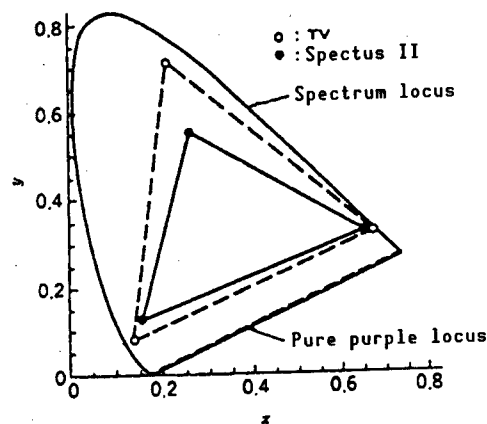


Figure 8. Reproduction Range of Color

With this structure, there is no unevenness of chromaticity, and the luminous intensity and joints between display elements are made inconspicuous.

3.1.3 Structure of Display Part

The display part structure is shown in Figure 9. Three liquid crystal units are put together in the intermediate module, which is attached to the moving module, which, in turn, is attached to the frame. The backlight is a three wavelength type compact fluorescent lamp, and this is attached to the moving module.

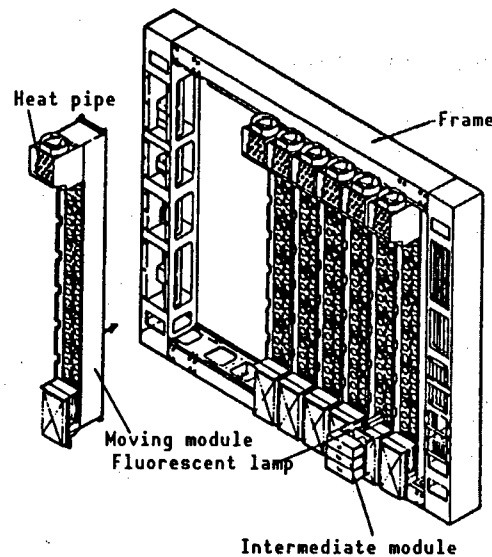


Figure 9. Structure of Display Part

The characteristics and specifications of the display part are shown in Tables 2 and 3.

The most significant, the S200 (screen size 200 inches), has 746,496 pixels and is able to provide four division displays and highly detailed images.

Table 2. Characteristic of Display Part

Light source	High luminous intensity fluorescent lamp (BB)
Element array	7.2 mm pitch matrix array
Monitoring distance	More than 3 m
Luminous intensity	300 cd/m ²
Contrast	60:1
Color reproducibility	Same as general television
Color temperature of white	9,300 K
Display gradation	64
Display speed	60 field/second
Response speed	Less than 30 ms
Established environment	General indoors

Table 3. Specifications of Display Part

Type	S90	S100	S140	S200
Diagonal length (inches)	89	102	136	204
Screen size (m)	1.296x1.843	1.555x2.074	2.074x2.765	3.120x4.155
Number of pixels	180x256x3 138,240	216x288x3 186,624	288x384x3 331,776	432x576x3 746,496
Electricity consumption (kW)	5.5	7	13	
External dimensions	2.2x2.6 x0.52	2.5x2.8 x0.52	3.2x3.6 x0.52	4.6x5.2 x750

The installation configuration can be the self-standing type, ceiling suspension type, or wall embedding type.

3.1.4 System Composition

(1) Signal Source

The system composition is shown in Figure 10. It has a character graphic system employing a personal computer, in addition to the audiovideo (AV) system for sufficiently exhibiting the functions of an image information media. While these signals are operable in a concentrated manner by the AV controller, it is possible to provide these signals with an automatic sending function.

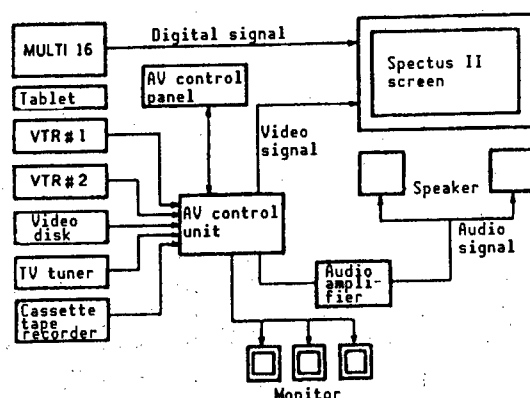


Figure 10. System Composition

(2) Image Control Part

The structure of the image control part is shown in Figure 11, and it allots image signals to the liquid crystal unit together with conducting the digital signal processing necessary for high image quality display.

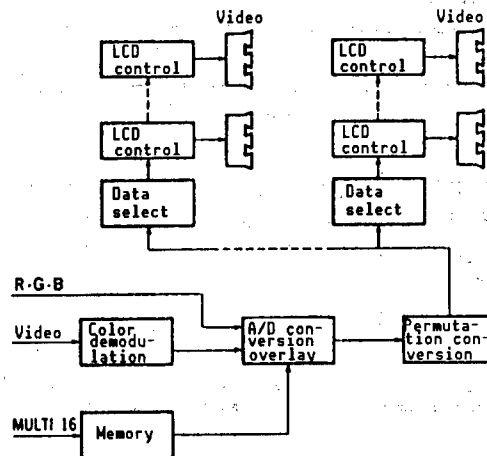


Figure 11. Composition of Image Display Part

Since the pixel row in the liquid crystal unit does not coincide with the scanning order of the video signals, allotment is made to the corresponding liquid crystal unit by the permutation conversion circuit after the digitalized RGB signal has been stored once in the frame buffer. In addition to the correction of the voltage versus transmittance characteristic of liquid crystal, the gamma correction, one that has taken the visual characteristic of man into consideration, is conducted independently. The gamma correction is eight bits for input and 16 bits (64 gradation) for output.

Moreover, the response time is slow when the drive amplitude is small for the time response characteristic of liquid crystal, and this deteriorates the image quality in the dark part of the image. In order to prevent this, a correction signal (nonlinear) is generated by utilizing the differential signal from the signal one frame ahead, and thereby improving the image quality.

3.2 Example 2 (Liquid Crystal Astrovision: Matsushita Communication Industrial Co., Ltd., and Matsushita Electric Industrial Co., Ltd.)

This, similar to example 1, is a full color image display with a diagonal screen size equivalent to from 100-200 inches. The pixel (single color pixel) pitch is 5 mm vertically and 6.6 mm horizontally.

3.2.1 Liquid Crystal Unit

The display unit of example 2 expands the effective area of the panel by using a light guide, as shown in Figure 12, covers the panel end without pixels, and is intended to effectively eliminate the joints.

Since the output beam of the liquid crystal has a directional property according to the orientation direction, the luminous intensity drops in the direction which does not coincide with the light guide direction. The orientation direction is changed for the upper and lower sides of the panel, and the luminous intensity on the panel surface is made uniform to prevent this. An aluminum vapor deposited plastic is used for the light guide, and the depth of this light guide is 20 mm.

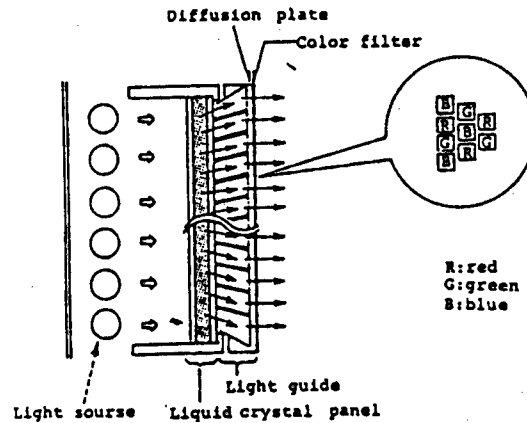


Figure 12. Liquid Crystal Units Jointly Using Light Guide

The GH liquid crystal, the characteristics of which are shown in Table 4, is utilized.

Table 4. Characteristics of Display Unit

Panel size (mm)	200 x 267
Number of pixels	40 x 40
Pixel pitch	Longitudinal 5 mm, horizontal 6.6 mm
Contrast	50:1
Luminous intensity	200 cd/m ²
Light guide depth	20 mm

3.2.2 Structure of Display Part

The structure of the display part is shown in Figure 13, and the three types of display parts shown in Table 5 have been prepared for standard screen sizes.

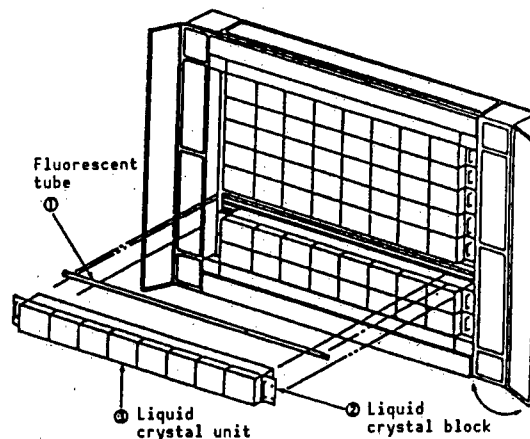


Figure 13. Structure of Display Part

Table 5. Specifications of Display

Screen type	I	II	III
Screen size (m)	1.6 x 2.1	2.2 x 2.9	3.2 x 4.3
No. of liquid crystal units	8 x 8	11 x 11	16 x 16
No. of pixels	102,400	193,600	409,600
Electricity consumption (kW)	5	9	17

4. Conclusion

The pixel pitch of several millimeters and the luminous intensity of about 200-300 cd/m² are available in displays in which direct-view-type liquid crystal panels are arrayed as modules, and these displays are utilized as the image message system with a screen size equivalent to about 100-200 inches that is intended for indoor open space.

The development of a highly detailed direct-view-type display which has further shortened the pixel pitch is expected in the future. Research such as that on the system of arraying composite CRTs, the system of expanding the image by using optical fibers and on the trend of developing directly devices of large diameters, in addition to the lattice constant system mentioned here, are being promoted in this direction.

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Liquid Crystal Spatial Light Modulators, Optical Computing

906C0054H Tokyo SENMON KOSHUKAI KOEN RONBUNSHU in Japanese Jan 90 pp 71-77

[Article by Yoshiaki Ichioka, Faculty of Technology, Osaka University]

[Text] 1. Introduction

Optical computing is a new research field that aims at the development of new large-capacity information system optical computing by taking full advantage of such features as ultra parallel characteristics, high speed, multiple wavelength, and noninductive properties of light, and it is positioned at the center of optical technologies for the next generation. The potential of an optical computer was suggested immediately after the laser was invented, but it was only during the 1980s that people really started to be concerned about it. Research on a comprehensive system concept and studies from aspects of both software and hardware are necessary for the realization of an optical computer. Research in this field has also rapidly progressed during the past 10 years.

The idea of trying to utilize light for information processing has been around for a long time; however, it is just now that the first generation optical information system based on the time series processing of light, such as the CD and optical memory, have finally been put to practical use. The reason that an epochal optical information system utilizing the essential features of light has not yet been realized is that the optoelectronics devices necessary for the preparation of the optical information system are undeveloped. However, this situation is suddenly changing and the time for developing new optoelectronic devices had rapidly ripened. Moreover, acting in concert with this, research on the software aspect as well, involving system composition and parallel operation algorithm, is progressing at a fevered pitch.

The recent performance improvement and the R&D speed of liquid crystal display elements are spectacular. Various liquid crystal display systems have been put to practical use by this and the fields of various information display systems, including the thin type television, are forming large markets. There are fields that have quietly watched the practical applications of such liquid crystal display elements with a zealous look and have been overjoyed by this trend. These fields include optical computing and optical information processing. Putting the spatial light modulators to practical use had been

long hoped for by those concerned with these fields. The reason for this was that the greatest bottleneck of optical computing research existed in the absence of an erasable high performance spatial light modulator to replace the photo film. The optical information processing and optical computing fields will enjoy a great benefit by the development success of liquid crystal light modulators, and rapid development will be achieved in the next few years. Such symptoms have already appeared in various countries all over the world, and research utilizing liquid crystal display elements and liquid crystal spatial light modulators has increased explosively.

A summary of the current condition of active optical computing research will be given and explanations will be made applying liquid crystal light modulators to optical information processing during the current stage.

2. Current Status of Optical Computers

Optical computers are largely classified into the following four categories, and research is being conducted accordingly.

- | | |
|---|--|
| 1. Analog optical computer | Real time property, exclusive parallel processor |
| 2. Optical-electronic computer
(Optoelectronic computer) | Two-dimensional parallel optical functional device |
| 3. Parallel digital optical computer | Parallel general-purpose processing, parallel image processing |
| 4. Optical neural computer | Parallel nonlinear processing |

The analog optical computer is an exclusive parallel optical computer system serving special purposes, such as the two-dimensional Fourier transformation and pattern collation. It uses analog optical information processing technology based on the various properties of light. Although the ultra-parallel characteristic is maintained since it utilizes analog optical operations, such defects as lacking in computing precision, repetitive computing functions, and general-purpose properties were found. A new development is also seen in this field whose history is as long as that of optical information processing. Research is active for the image identification system and associative system that aim at practical application making real time parallel projection possible on a global basis. Moreover, the development of a multidimensional parallel processing system that cleverly unites spatial multidimensions and wavelength multiplicity has also been launched. The realization of a system with program potential can be expected with progress in the high performance realization of spatial light modulators.

The optoelectronic computer is an optical pulse-utilizing optical electronic computer which uses the properties of light which are superior to those of electrons (electro-noninterference characteristic, magnetic field, does not require grounding, and low loss property of signals by optical transmission in which large fan-out and fan-in are adoptable). It is an optoelectronic computing system in which the area suitable for light and electrons are

executed in high-speed optical or electron elements, respectively, and which conducts signal communications between them by optical connection. An optical computing system that conducts the computing and storage of signals by light by using new optical functional devices, etc., is also being studied.

The system is composed by putting new optical functional devices, such as the optical bistable device and optical electronic integrated circuit (OEIC), to practical use. The limit of signal communications speed between very large-scale integration (VLSI) and between chips, which currently represents a bottleneck in improving the computing speed of electronic computers, is improved by utilizing light connections. The configuration and functions of the computer, which is a times series digital computing system, are close to those of electronic computers. The main objectives are high-speed optical communications applications and the development of a high-speed general-purpose computer with about a three-digit-higher computing capacity than that of a supercomputer.

Minimizing the size and increasing the speed of devices have been achieved sufficiently, and an optical computer will emerge with the highest feasibility when the two-dimensional parallelling of the light source, theoretical device, and memory device are realized. The system using OEIC is a composite-type optoelectronic information system which uses optical connections for the signal connections of the electronic circuits and input/output circuits, as well as within devices and between devices. OEIC is an optoelectronic functional device that can be realized as an extension of the present technology, and research on OEIC is progressing rapidly. Research on the light-aided electronic computer which introduces an optical computing system into an electronic computer has shown active development in other countries, particularly the United States.

The parallel digital optical computer is a large capacity information system which has taken full advantage of the properties of ultrahigh speed, wide band, ultra-parallel computing and digital processing flexibility, which are significant characteristics. The ultra-parallel computing concept is adopted in all parts of the computer (input/output, memory, and computing). Various processing technologies traditionally connected with optics are introduced into the information system by changing the point of view. Moreover, digital technologies fostered by the digital computer development history will be utilized to the maximum extent. Of course, the highly regarded parallel analog processing (optical information processing) of light will also be utilized as occasion calls. The objective is the development of a high-speed image processing and ultrahigh-speed general-purpose parallel computer. It has been discovered that a parallel theoretical computing function exists in optical information technology for the parallel two-dimensional binary input signal, and research has progressed with this regarded as the turning point. Various system architectures and parallel computing principles are currently being proposed, both at home and abroad. A parallel processing programming technique using a new computing principle is being developed, together with the progress in architectural research.

The optical neural computer is a new parallel optical computing system based on the concept of a neural network. The neural network that has suddenly attracted attention recently involves research using light. It has aimed at the construction of a system capable of replacing the intellectual information processing capacity conducted by the human brain, such as, for example, the pattern retrieval capacity and pattern recognition capacity. It is a new system that is capable of executing distributed processing, shared processing, and the processing of ambiguities or the processing of results, which conventional computers have lacked. It aims at solving random problems, such as pattern recognition, etc., rather than structural problems like the numerical calculations made by electronic computers. Research on this is currently being promoted throughout the world. This system is composed of an enormous number of devices. The parallel signal connections between devices, threshold processing (nonlinear processing), and parallel distributed processing are necessary for the execution of this system. The parallel property of light is adjusted well in parallel signal connections and parallel distributed processing. However, since research involving the neural network is still in the basic stage, no presentation of concrete architecture has yet been made.

In addition to the four categories mentioned above, a system architecture comprising these categories will be announced in the near future. The utilization technology of nonlinear optical phenomena, such as high-speed optical switching technology, three-dimensional hologram technology and phase conjugation, the paralleling of optical functional devices including the semiconductor laser, the practical application of spatial light modulators now realizing high-level performances, and the development of an ultrahigh resolution lens system which has been supported by the conventional progress in optical technology, will become important topics for the realization of all systems.

3. Liquid Crystal Spatial Light Modulator

The spatial light modulator is a device which reads the information stored in the device and applies a parallel modulation to the input optical signal. Information is written by an optical or electronic system. Information that has been written (generally, two-dimensional image information) modulates the incident real light to the device and outputs it as transmitted or reflected light. Photographic emulsion film has been utilized in the past as the modulation device. It is regrettable but, against the two-dimensional signal, the photographic film fulfills only the function of Read Only Memory. In contrast to this, the spatial light modulator is an erasable modulation device with write and read capabilities with regard to two-dimensional signals. Therefore, a dynamic range against resolution, sensitivity, and input optical signals, response speed, operation ease of write and read, and superior operationability, equivalent to that of a photographic film, are demanded as functions of the spatial light modulator. A device satisfying all of these performances has not yet appeared. Generally, the optical constant of the material is changed to expedite the response speed.^{2,3} The liquid crystal spatial light modulator using the nematic liquid crystal and ferroelectric liquid crystal, PROM device using the ferroelectric crystal,⁴ MSIM combining the image tube, microchannel plate and ferroelectric crystal,⁵ CCD-LC device combining CCD with liquid crystal,⁶ Si-PLZT device,⁷ variable surface mirror device (DMD),⁸ and self-electrooptic effect device (SEED) bistable mode device⁹

have appeared as devices having dynamic characteristics. The characteristics¹⁰ of the optical write-type spatial light modulators are shown in Table 1. These modulators are mainly used for applications such as optical information processing, optical neural network, etc.

Table 1. Characteristics of Optical Write Spatial Light Modulator¹⁰

Device (Ref)	Active size length or diameter (mm)	Resolution at 50% MTF (lp/mm)	Cycle time (ms)	Optical switching energy* (pJ)
Hughes LCLV	25	16	100	50
Hoechst Celanese	40	38	25	36
α -Si:H/nematic	38	>35	100	2
α -Si/nematic	25	5	1.4	2.5
α -Si:/FLC	40	28	0.5	0.2
α -Si:H/FLC	10	38	0.3	0.11
Hamamatsu micro-channel	16	10	150	0.75
PROM	5.8	5	<0.1	500
SEED bistable mode	0.5	5	~0.001	180

*Optical switching energy per bit = intensity x [write-time/ (2 x resolution)].

The liquid crystal spatial light modulator is also called the liquid crystal light valve (LCLV). The progress in recent research is eye-opening, and devices having various compositions have been developed. The general composition of the optical write-type liquid crystal spatial light modulator is a sandwiched structure of optical abrasive glass, transparent conductive electrode, photoconductor layer, dielectric reflection coating, orientation layer, liquid crystal, orientation layer, transparent electrode, and optical abrasive glass. The writing light is input from the right side, the reading light is irradiated from the left side, and the output signal is extracted as the reflected light. Therefore, different wavelengths can be used for the writing light and reading light. Figure 1(a) is the composition of Hughes LVLC using the nematic liquid crystal, while Figure 1(b) shows the composition of α -Si:H/FLC (LAPS-SLM¹²), which has recently been developed by Seiko Electronics Co., Ltd. Please refer to the literature for the details, operations, etc., of the device. As is universally well known, the features of liquid crystal spatial light modulators are that low voltage operation is possible and the fabrication of a large area device is impossible, and the defect is that the contrast is low.

4. Application of Liquid Crystal Spatial Light Modulator to Optical Computing

The research history of liquid crystal spatial light modulators (LCSLM) is comparatively long, with the Hughes LCLV using a nematic liquid crystal having already been announced during the latter part of the 1970s. This device was sold on the market, but its price was incredibly high. Research on an image

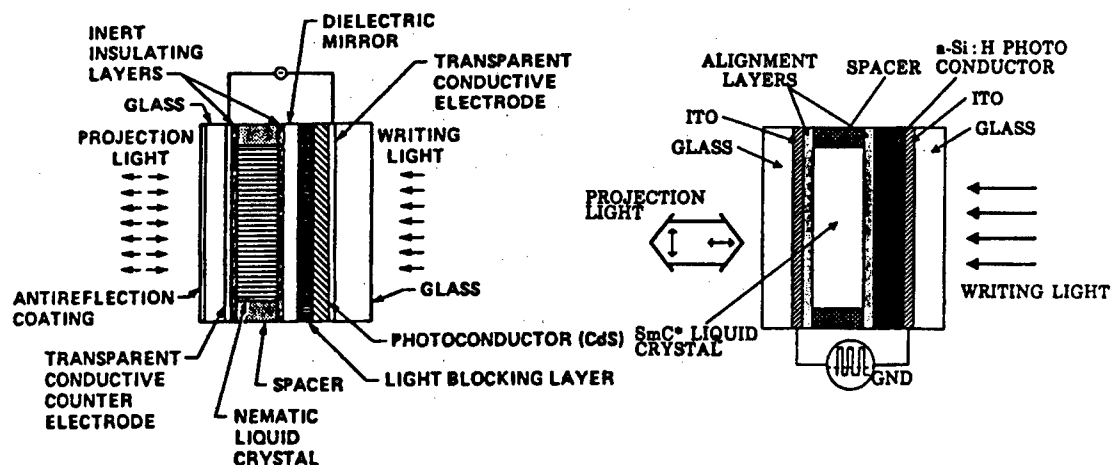


Figure 1(a). Hughes LCLV¹¹

1(b). LAPS-SLM¹²

computing optical bistable optical system,¹³ optical logic gate,¹⁴, etc., using this LCLV have been announced.

With the liquid crystal television (LCTV) having been put to practical use and being made available at a low price recently, much research is seen on the simple real time optical image system (analog optical computing system) utilizing LCTV.

Li, et al.,¹⁵ announced a portable image comparator by using two LCTVs with polarizing plates removed, a white light source, digital delay unit, and video recorder. They have realized a real time image difference by using a television and digital frame memory, and have prepared a simple moving image tracing filter system. There is also the high precision real time moving image racing system using LCTV and a position sensor.¹⁶ These applications utilize the television characteristics as they are.

Various experiments are being conducted regarding LCTV as the spatial light modulator. These include the utilization,¹⁹ etc., of the coherent optical correlator,¹⁷ computer hologram drawing filtering system,¹⁸ and incoherent white color processor input device. Since the two-beam hologram is used in these applications, an extremely high resolution property is demanded in the device. Research on optical correlated computing using the phase-only filter and phase-only binary filter has been active recently.²⁰ The image identification capacity is remarkably improved when these filters are used. The kinoform can be utilized for this filter in place of the hologram. The liquid crystal device is utilized as the optical phase modulator (refractive index modulator) in this application. The problem with resolution mentioned above can be avoided in this case.

The variable-focal-length lens represents an interesting application of the liquid crystal device. This lens is called the liquid crystal adaptive lens (LCAL). This lens performs the function as a plate-type graded-index lens. The layout of the experimental device realizing LCAL conducted at UCD [expansion not provided] is shown in Figure 2.²¹ The LCAL cell consists of multiple

array-shaped openings, and the focal beam effect, focal distance, and focal position (horizontal direction) of light are controlled by the voltage (parabolic applied voltage in the drawing) applied to each electrode array. The focal beam effect utilizes the refractive index change of the liquid crystal layer caused by the voltage applied to each opening. The convex cylinder lens effect is realized in the one-dimensional cell shown in the drawing. It is necessary to utilize two liquid crystal cells to generate the spherical lens effect. The cell has been coated with 25 nm ITO. The composition of sandwiching a liquid crystal (RO-TN-403) at 20, 25, or 75 μm between two glass plates, 3.2 mm thick, has been adopted. Moreover, 64 openings (electrodes), 30 μm in width, have been etched at 60 μm intervals for ITO on top of one of the glasses.

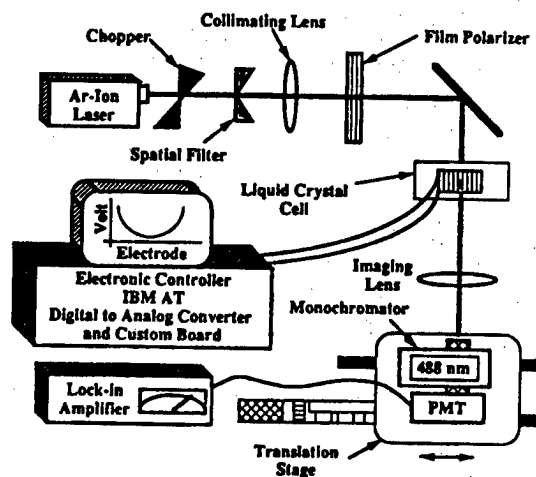


Figure 2. Experimental System for LCAL Realization¹²

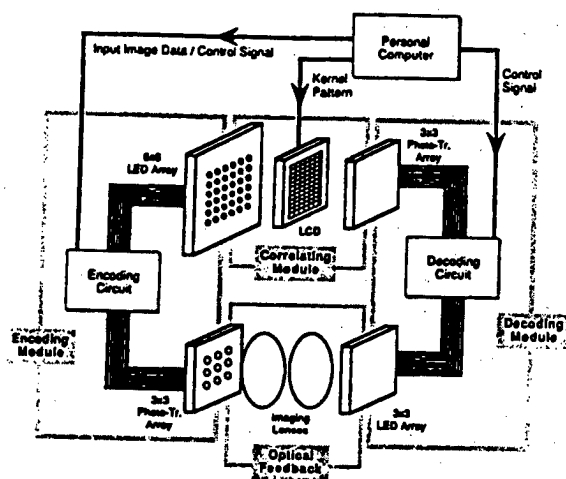


Figure 3. Block Diagram of Electronic/Optical Composite-Type OPALS Using LCTV²²

Experiments involving various parallel logic and parallel digital optical computing systems, assuming LCTV to be a discrete spatial light modulator, are also being conducted actively. Research on parallel binary logic and multiple

plating logic using LCTV are being conducted at New York State University, NTT, and Osaka University. Since the input signal can be written electronically in the case of LCTV, it excels in operationability and controllability, and can be used as an experimental system for the optical computing system. Figure 3 shows the block diagram of the parallel optical computing system: OPALS electronic/optical composite system of Osaka University.²² The matrix-type LCD (made by Matsushita) has been used, and is utilized for parallel logic computing, display of intermediate results, coding, etc.

The development of an active matrix-type spatial light modulator with a memory function utilizing the integrated semiconductor fabrication technology is close behind. This device is an electronic writing system and, since the individual devices composing the device array can be controlled externally, spatial variable and programmable processing is possible and can be utilized for various applications. An nMOS-SLM with a possible random access of 50×50 pixels has been announced at England's Edinburgh University.²³

Research on spatial light modulators using ferroelectric liquid crystals (FLC) has become active recently, with the FLC-SLM having been announced in various countries. As is well known, characteristics of FLC include high-speed response ($<100 \mu s$), low voltage operation ($\sim \pm 10$ V), low switching energy, memory, and electrical stability. Since FLC functions as an electronic controllable phase plate, many research projects utilizing this property have been announced. In particular, a Colorado University group is energetically conducting research on polarized light utilizing parallel logic, various turntable filters, parallel light connection, optical associative memory, and optical neural computing.¹⁰ Moreover, Cambon, et al.,²⁶ in France are conducting research on morphology by the binary logic based on polarization and spatial data shift by using FLCLV.

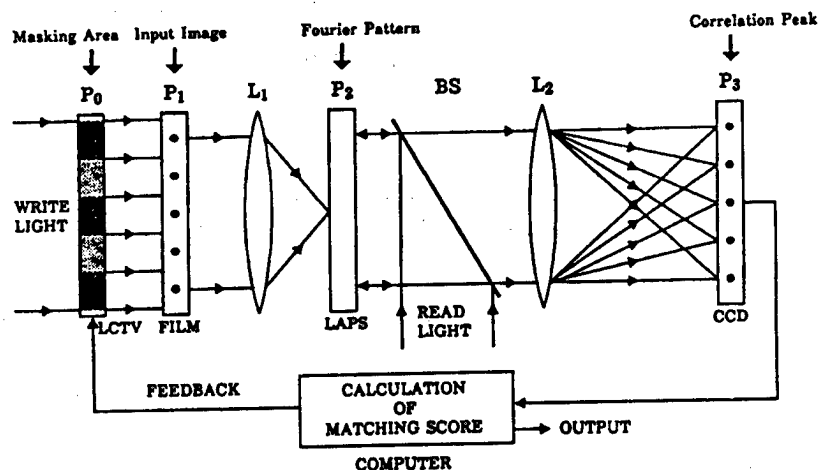


Figure 4. Joint Transform Correlator¹²

The development of FLC-SLM has also been launched in Japan. Figure 4 shows the recently-announced feedback joint transform correlator using the optical writing-type spatial light modulator LAPS-SLM (Figure 1(b)), offering high speed and high resolution. Superior processing results are available.²⁷

5. Conclusion

The spatial light modulator is an optical functional device that has been eagerly awaited for a long time in the fields of optical computing and optical information processing. The progress in liquid crystal device development is truly celebrated in that sense, and it is hoped that spatial light modulators with various new functions will also be developed one after another in Japan in the future. The main objective of liquid crystal device development now is the plane-type display.

The image system that will occupy the indisputable position in the high-degree information society, which will expand between now and the 21st century, is the more flexible new image system which will coexist with the television system. The reason for this is that these new image systems are inseparably bound with life in the society of man. Information handled in the image system are signals of extremely wide bands. The burden placed on the system will be too great when these signals are handled by means of the von Neumann-type computer alone. It is believed, as a matter of course, that an optical image system strong in parallel processing (parallel optical computing system) will become necessary. As a result, research on optical computing and optical information processing will become more and more important. Therefore, putting the key device, i.e., the spatial light modulator comprising such a system, to practical use becomes very important both socially and economically. When these matters are recognized, there is not the slightest doubt that the future development of the liquid crystal device field will involve acquiring the development ability of multifunction and large degree of freedom large image devices. A great expansion is anticipated.

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Present, Future Trends of Liquid Crystal Materials

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[Article by Naemura Shohei, Merck Japan, Ltd., Atsugi Laboratory]

[Text] 1. Introduction

Liquid quartz materials have mainly been put to practical use in applications to display devices. Aiming at coloring, highly detailing, large display capacity realization and large area realization, the development of liquid crystal display devices (LCD) by various operational modes is keenly competitive. There are the active matrix twisted nematic (TN) mode LCD, simple matrix super-twisted nematic (STN) mode LCD, electrically controlled birefringence (ECB) mode LCD, and ferroelectric LCD. Several different characteristics are demanded of liquid crystal materials according to the respective operational modes the basic physical properties of liquid crystal materials and conventional representative liquid crystal materials will be reviewed, and explanations will be made of recent liquid crystal materials and of the applicability of these materials to various operational mode LCDs.

2. Basic Physical Properties of Liquid Crystal Materials

The following physical properties of liquid crystal materials are important from the viewpoint of application to display devices.

Phase System and Phase Transition Temperature

A wide nematic phase temperature range and a smectic phase in the low temperature range according to the circumstances become necessary in liquid crystal materials using TN and STN. Moreover, there are many cases in which a wide chiral smectic C phase temperature range and the presence of the smectic A phase and chiral nematic phase in the high temperature range are necessary in liquid crystal materials for FLC. It is not possible to estimate accurately the phase transition temperature from the molecular structure under the present molecule statistic theory. The relationship of the ring system of the end group and skeleton with the coupling group, molecular length, etc., have been discussed experimentally.

Viscosity Coefficient

A liquid crystal material with a small viscosity coefficient, especially in the low temperature range, is desired from the relationship between the viscosity coefficient and display speed. Although it is the rotational viscosity (torsional viscosity) γ_1 which has an especially strong relationship with the display speed, it is often generally discussed by means of the bulk viscosity γ due to measuring convenience. It has been reported that the ratio value γ_1/γ of these is in the range of 3-8 in many nematic liquid crystal materials.¹

Elastic Constant

Elastic constants K_{11} , K_{22} , and K_{33} (Figure 1) for spray, twist, and bend are important in nematic liquid crystal materials. The size of the elastic constants controls the voltage-light transmittance characteristics profile (steepness of threshold characteristic, etc.), and has a particularly close relationship with the time-sharing driving property (display contrast). Theoretically, the elastic constant K_{ij} is correlated with the orientation order parameter S and molecular volume V_m by the following equation.²

$$K_{ij} = C_{ij} V_m^{7/3} S^2$$

Here, C_{ij} is the standardized elastic constant not dependent on temperature.

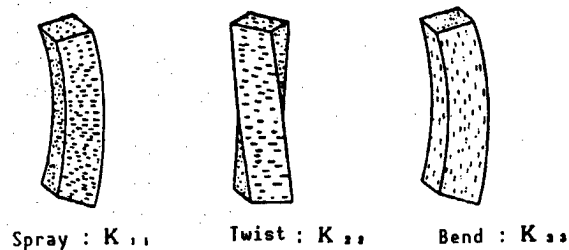


Figure 1. Three Types of Elastic Constants

Birefringence

Two refractive indexes, n_y and n_x , representing the direct orientation and orthogonal orientation, respectively, exist optically in the liquid crystal material of uniaxial crystal.

The sum value $\Delta n \cdot d$ of birefringence $\Delta n (= n_y - n_x)$ and the liquid crystal layer thickness d have a strong relationship with the color tone, display contrast, and visual angle characteristic.

Specific Dielectric Constant

An anisotropy also exists in dielectric constants. It is necessary that the specific dielectric constant anisotropy $\Delta\epsilon (= \epsilon_y - \epsilon_x)$ be positive in TN and STN, and that a negative $\Delta\epsilon$ exist in ECB. It is effective for the low voltage driving of the display device in both cases that the absolute value $|\Delta\epsilon|$ be large.

Specific Resistance

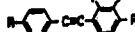
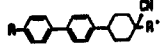
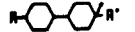
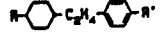
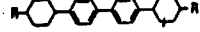
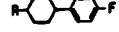
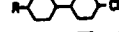
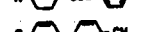
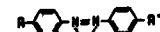
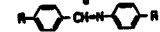
An anisotropy exists ultimately, but it is generally discussed by the bulk value ρ . A high specific resistance value is especially demanded in liquid crystal materials used for the active matrix LCD.

In addition to those mentioned above, consideration for more physical properties, such as the spiral forming force for chiral liquid crystal materials, spontaneous polarization, tilt angle, etc., especially for ferroelectric liquid crystal materials, are necessary. Moreover, actually-used liquid crystal materials are composed of several types of liquid crystal compounds mixed, and the additive property of the component compound physical property value does not necessarily hold true for the physical property of compositions.

3. Representative Liquid Crystal Materials and Their Physical Properties

The structures of representative liquid crystal compounds are shown in Table 1 in the approximate order of their development period. In the structural formula, R is the alkyl group and R' is the alkyl group, alkoxide group, cyano group, etc. The full-scale practical application of LCD started with the invention³ of cyanobiphenyl CB early in the 1970s. The chemical stability problem experienced by conventional materials, such as Schiff base, azoxy, etc., was conquered by cyanobiphenyl CB. Phenylpyrimidine PYP⁴ is characterized by the bend-spray elastic constant ratio K_{33}/K_{11} being extremely small. The value of K_{33}/K_{11} for the end group R' of an alkoxide group compound is smaller than that of the cyano group. The end group R' of a cyano group PYP is known as a compound in which the dielectric anisotropy is positive and large. The phenylcyclohexylcarboxylate ECH⁵ is a compound with a comparatively wide nematic phase temperature range and small viscosity. The end group R' of a phenylcyclohexylethane EPCH⁶ also is characterized by positive dielectric anisotropy and low viscosity. Phenyl sodium cyclohexylsulfamatehexane PCH⁷ is a useful compound with a small birefringence and low viscosity. Cyclohexylcyclohexane CCH⁸ shows a smaller birefringence, but the viscosity is high. The CCN⁹ combining the CCH skeleton and molecular short axial direction cyano group is the first practical use material that possesses a positive and large dielectric anisotropy. As mentioned above, a three-ring or four-ring structure compound to which a benzene ring and cyclohexane have been added to the two rings of the skeleton structure is also used. BCH, ECCP, CBC, etc., serve as representatives. These compounds have a high nematic anisotropy liquid phase transition temperature and are effective for the expansion of the nematic phase temperature range of liquid quartz compositions, but the viscosity tends to be high.

Table 1. Representative Liquid Crystal Compounds

1990		SFM
		DFS
		NCB
		ECCP
		CCN
		EPCH
1980		CBC
		PCH-F
		CCH
		BCH
		PCH
		ECH
		CB
		PYP
1970		Azoxys
		Schiff's bases

4. Recent Liquid Crystal Material--Fluorinated Structure and Its Effect

After experiencing the trend mentioned in the preceding paragraph, fluorine substitution of the skeleton ring structure and compounds of a structure having a fluorine substituent at the end have been developed recently and are attracting attention. The DFS (difluoro substituted) compounds¹⁰ possessing 2-,3-difluorobenzene ring and compounds¹¹ called SFM (super-fluorinated materials) in which the trifluoromethoxy group serves as the end group, as shown in Table 1, are such compounds. Explanations of the fluorinated effect will be given.

Table 2 shows examples of cases when the second, third, fifth, and sixth positions of the benzene ring have been fluorinated in compounds with a positive dielectric anisotropy which possess a cyano group in the fourth position of the benzene ring. Although the fluorinating of the orthoposition of the cyano group is effective for increasing the positive dielectric anisotropy, viscosity is also increased. Fluorinating more than this does not contribute to dielectric anisotropy and lowers the stability of the nematic phase. Birefringence tends to decrease with an increase in the number of fluorine atoms.

Table 2. Fluorinating Effect of Benzene Ring in Compounds With a Positive Dielectric Anisotropy

Chemical structure	Phase transition temperature	$\Delta\epsilon$	ν [mm ² /s]	Δn
	[°C] C 64 N (57) I	+25	56	0.16
	C 30 N (24) I	+40	65	0.15
	C 38 I	+24	75	0.14
	C 72 I	+23	68	0.11

A more favorable effect by the fluorinating of the skeleton ring structure is seen in compounds having an alkoxy group in the fourth position of the benzene ring. Table 3 shows the fluorinating effect of the second and third positions in cyclohexanecarboxylate. Viscosity virtually does not change, but the negative dielectric anisotropy increases with the fluorination progress from 3-fluoro to 2-3 difluoro. Moreover, the increase in the positive dielectric anisotropy and the lowering of viscosity effects are available at the same time by the 2-,3-difluoro substitution structure in tolane compounds having -C≡C- coupling in the skeleton. Examples are shown in Table 4. A typical basic skeleton providing a negative dielectric anisotropy to liquid crystal compounds is shown in Table 5. It is known that DFS compounds possess superior characteristics since both the dielectric anisotropy and low viscosity coexist. The 2-,3-difluoro substitution structure induces the smectic C phase or has a stabilizing effect in liquid crystal compounds showing a smectic phase. Examples are shown in Table 6. These DFS compounds are effective as components of ferroelectric liquid crystal compositions.

Table 3. Fluorinating Effect in Cyclohexanecarboxylate

Chemical structure	Phase transition temperature	$\Delta\epsilon$	ν [mm ² /s]
	[°C] C 57 N 86 I	-1.2	19
	C 49 N 59 I	-1.9	21
	C 51 N 63 I	-4.6	18

Table 7 shows the fluorine substitution effect of the fourth position of the benzene ring. A positive dielectric anisotropy is available according to the end group fluorine substitution structure, but the size is inferior to that of the cyano group. However, viscosity is low when compared to the end cyano group structure. Table 7 also shows the 3-,4-difluoro substitution structure

Table 4. Fluorinating Effect in Tolane Compounds

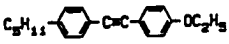
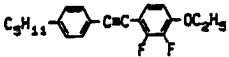
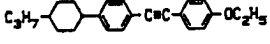
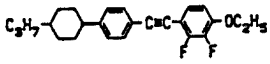
Chemical structure	Phase transition temperature [°C]	$\Delta\epsilon$	ν [mm ² /s]
	C 61 N 89 I	+0.2	20
	C 57 N 61 I	-4.4	17
	C 110 N 253 I	±0	36
	C 84 N 229 I	-4.1	27

Table 5. Basic Skeleton Providing a Negative Dielectric Anisotropy to Liquid Crystal Compounds

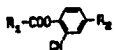
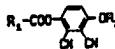
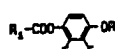
Chemical structure	$\Delta\epsilon$	ν [mm ² /s]
	-4	≈ 200
	-20	≈ 400
	-6	≈ 100
	-8	≈ 70
	-6	≈ 20

Table 6. 2-,3-Difluoro Substitution Effect in Liquid Crystal Compounds Processing a Smectic Phase

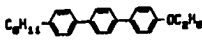
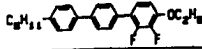
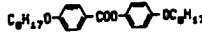
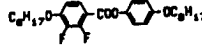
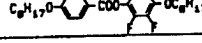
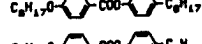
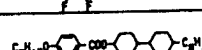
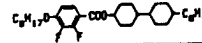
Chemical structure	Phase transition temperature [°C]	$\Delta\epsilon$	ν [mm ² /s]
	C 234 S _E 237 S _A 242 N 248 I		
	C 105 S _C 135 N 185 I	-4.2	49
	C 83 S _C 74 N 91 I		
	C 48 S _C 71 N 82 I	-2.7	120
	C 54 S _C (38) N 60 I		
	C 54 S _A 64 N 66 I	+0.4	70
	C 37 S _C 49 N 57 I	-2.7	82
	C 80 S _A 140 N 182 I	-0.8	82
	C 90 S _C 98 N 170 I	-2.1	82

Table 7. Fluorinating Effect of Third and Fourth Positions of End Group Benzene Ring

$\text{C}_3\text{H}_7\text{---}(\text{C}_6\text{H}_4)\text{---}(\text{C}_6\text{H}_4)\text{---}(\text{C}_6\text{H}_3\text{XY})\text{---X}$				
Y	X	Phase transition temperature [°C]	$\Delta\epsilon$	ν [mm ² /s]
H	F	C 90 N 158 I	+7	16
F	F	C 46 N 124 I	+9	21
H	CN	C 79 N 241 I	+13	94
F	CN	C 53 N 204 I	+19	100

$\text{C}_3\text{H}_7\text{---}(\text{C}_6\text{H}_4)\text{---}(\text{C}_6\text{H}_4)\text{---C}_2\text{H}_4\text{---}(\text{C}_6\text{H}_3\text{XY})\text{---X}$				
H	OCH_3	C 88 S ₂ 140 N 176 I	±0	23
F	OCH_3	C 93 S ₂ 109 N 160 I	-1	44
H	F	C 45 S ₂ 83 N 134 I	+6	18
F	F	C 20 S ₂ 50 N 117 I	+9	21
H	CN	C 69 N 196 I	+12	75
F	CN	C 72 N 170 I	+18	90

Table 8. Fluorinating Effect of End Group in Three Ring Structure

$\text{C}_3\text{H}_7\text{---}(\text{C}_6\text{H}_4)\text{---}(\text{C}_6\text{H}_4)\text{---}(\text{C}_6\text{H}_4)\text{---X}$			
X	Phase transition temperature [°C]	$\Delta\epsilon$	ν [mm ² /s]
CH_3	C 62 S ₂ 108 N 177 I	±0	22
F	C 90 N 158 I	+7	16
OCF_3	C 38 S ₂ 69 N 154 I	+9	16
CN	C 79 N 241 I	+13	94

$\text{C}_3\text{H}_7\text{---}(\text{C}_6\text{H}_4)\text{---}(\text{C}_6\text{H}_4)\text{---C}_2\text{H}_4\text{---}(\text{C}_6\text{H}_4)\text{---X}$			
OCH_3	C 88 S ₂ 140 N 176 I	±0	23
CH_3	C 45 S ₂ 127 N 153 I	±0	14
F	C 45 S ₂ 83 N 134 I	+6	18
OCF_3	C 24 S ₂ 76 N 134 I	+8	14
CF_3	C 50 S ₂ 114 N 117 I	+12	23
CN	C 69 N 196 I	+12	75

effect. Similarly as in the case of the end cyano group, the positive dielectric anisotropy increases with the fluorinating of the ortho position (third position), but viscosity also increases.

SFM is the compound that has realized a positive dielectric anisotropy of about the same level as that of the 3-,4-difluoro substitution structure without increase viscosity. Table 8 shows the dielectric anisotropy and viscosity difference according to the end group structure in the three ring skeleton structure, which is the same as that in Table 7. It is known that SFM

possessing the $-\text{OCF}_3$ group has an extremely low viscosity, together with a dielectric anisotropy of the same level as that in the 3-,4-difluoro substitution structure of Table 7. Various skeleton structure SFM characteristic examples are shown in Table 9. SFM is also characterized by the fact that it is extremely stable thermally, chemically, and photochemically.

Table 9. Structure and Characteristics of Representative SFM Liquid Crystals

Chemical structure	Phase transition temperature (°C)		$\Delta\epsilon$	ν (mm ² /s)
	C 14		I +7.1	4
	C 20		I +7.2	6
	C 37	N (34.8)	I +6.6	8
	C 62 S _B 73	N 166	I +9.2	17
	C 88 S _B 126 S _A 163	N 198	I +9.7	17
	C 44 S _B 108	N 139	I +8.1	16
	C 43 S _B 128	N 147	I +8.9	16

5. Application to Display Devices

5.1 Simple Matrix LCD Liquid Crystal Materials

The steepness of the electrooptical characteristic which controls the time-sharing drive characteristics is one of the important factors in simple matrix LCDs, such as STN, ECB, etc., utilizing the cumulative response. As shown in Figure 2, an effective way to improve the steepness (approach γ to 1) is to make the bend-spray elastic constant ratio K_{33}/K_{11} of the liquid crystal material large and the dielectric constant ratio $\Delta\epsilon/\epsilon_1$ ($= \epsilon_{\parallel}/\epsilon_1 - 1$) small in STN-LCD.¹² From this viewpoint, there are many cases when liquid crystal compositions are composed mainly of PCH, which has a comparatively large K_{33}/K_{11} value. Moreover, the mixture of DFS compounds with a negative dielectric anisotropy and large ϵ_1 value is effective for making the dielectric constant ratio small. These compounds are also preferable from the viewpoints of comparatively low viscosity and display speed. It is also necessary to make the spray elastic constant K_{11} large, together with making the viscosity of the liquid crystal material small, to accelerate the display speed of STN-LCD. Compounds having an ethylene coupling, such as ECCP, are effective in this regard.

It is necessary for liquid crystal compositions using ECB-LCD to possess a negative dielectric anisotropy. Therefore, DFS and CCN with a negative dielectric anisotropy and low viscosity become the main components. Similarly, as in the case of STN-LCD, the greater the K_{33}/K_{11} value of the elastic constant ratio, the better the steepness. However, making the value $\Delta\epsilon/\epsilon_1$ ($= \epsilon_{\parallel}/\epsilon_1 - 1$) small for the dielectric constant ratio contributes to improving the steepness. Figures 3 and 4 are calculation examples¹³ for obtaining steepness and the relationship with these liquid crystal material values.

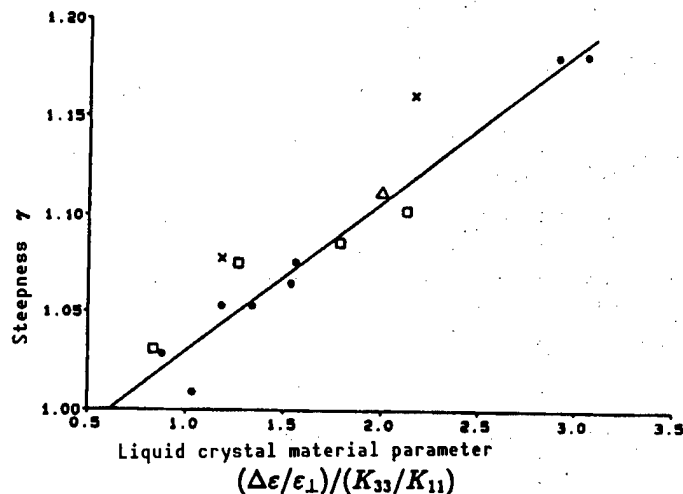


Figure 2. Relationship Between Steepness γ and Liquid Crystal Material Parameter $(\Delta\epsilon/\epsilon_1) (K_{33}/K_{11})$

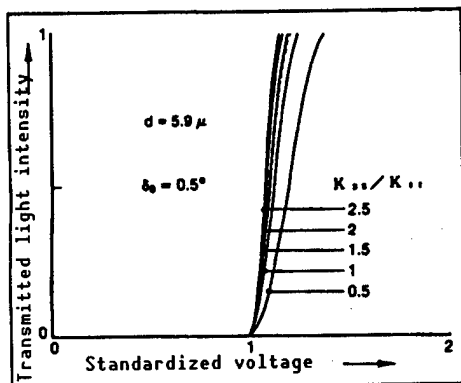


Figure 3. Electrooptical Effect of ECB-LCD (Elastic constant ratio dependence)

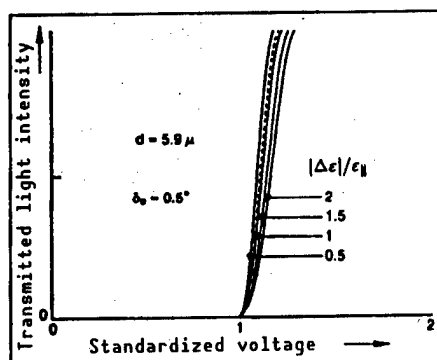
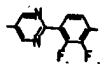


Figure 4. Electrooptical Effect of ECT-LCD (Dielectric constant dependence)

Since a pulse response is utilized in the writing and erasing of displays in the ferroelectric LCD, an extremely high-speed response and superior memory property are demanded. A large spontaneous polarization and low viscosity are desired in liquid crystal materials for high-speed response, but since a liquid crystal material with a large spontaneous polarization lowers the memory property, it is preferable to promote low viscosity realization. There are currently many cases in which ferroelectric liquid crystal compositions are composed by mixtures of about 90 percent smectic C phase materials and about 10 percent ferroelectric chiral dopants. Therefore, it is necessary to realize liquid crystal compositions possessing a low viscosity and wide smectic C phase temperature range. An example has been reported in which DFS compounds effective for the stabilization of the smectic C phase have brought about the expansion of the smectic C phase temperature range in the mixed system as well.¹⁴ Figure 5 is a phase diagram that shows the effect of smectic C phase temperature range expansion by a PYP mixture (PYP-90m: C_9H_{19}  OC_mH_{2m+1}) and PYP-DFS (PYP-90mFF: C_9H_{19}  DC_mH_{2m+1}).

Since such liquid crystal compositions do not require the mixing of multi-ring structure compounds for temperature range expansion in addition to PYP, which itself is of comparatively low viscosity, they represent low viscosity materials effective for high speed. Moreover, it is known that the negative dielectric anisotropy possessed by combining it with the drive method, which is termed the AC stabilizer method.

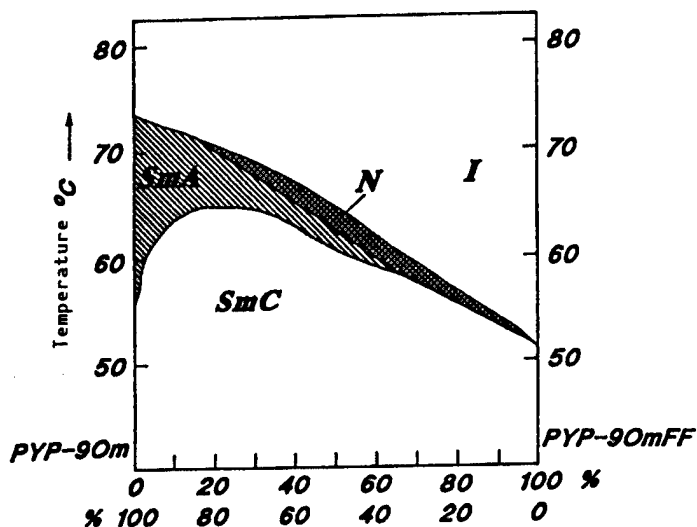


Figure 5. Phase Diagram of Mixed System of PYP-90m and PYP-90mFF

5.2 Active Matrix LCD Liquid Crystal Materials

One of the important characteristics demanded of active matrix LCD liquid quartz materials is high specific resistance. The reason for this is that the electric charge for liquid crystal drive becomes attenuated within the frame time of the display screen when the resistance value of the liquid crystal layer of the LCD panel is small. As shown in Figure 6, a larger bulk specific resistance ρ is available in a liquid crystal material with a smaller mean dielectric constant $\bar{\epsilon}$ ($= (\epsilon_{\parallel} + \epsilon_{\perp})/3$).¹⁵ As a result, it has actually been measured that the RC time constant τ_{RC} corresponding to the electric charge attenuation becomes longer when using a liquid crystal material with a smaller mean dielectric constant $\bar{\epsilon}$. The results are shown in Figure 7.¹⁵ It can be seen from such a viewpoint that the SFM liquid crystal materials exhibiting the proper dielectric anisotropy and an extremely small $\epsilon_{\perp}$ value are preferable to compounds of a structure possessing the 3-fluoro-4-cyano substitution benzene ring in which the $\epsilon_{\perp}$ value increases together with the dielectric anisotropy. Moreover, SFM has a low viscosity and is also superior in display speed. Generally, compounds with fluorine system end group excel in stability in comparison with the cyano group compounds and, as shown in Figure 8, the decrease in the RC time constant is extremely small under the high temperature preservation condition of 150° as well. SFM has superior stability and favorably affects the environmental resistance of the active matrix LCD.

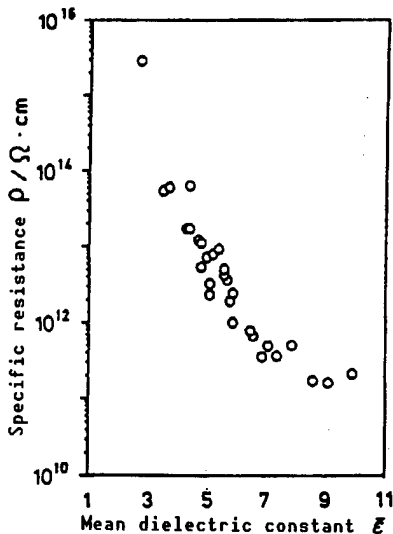


Figure 6. Relationship Between Specific Resistance and Mean Dielectric Constant of Liquid Crystal Material

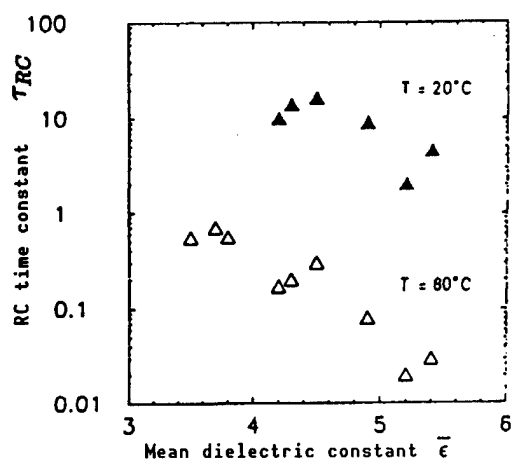


Figure 7. Relationship Between RC Time Constant and Liquid Crystal Material Mean Dielectric Constant

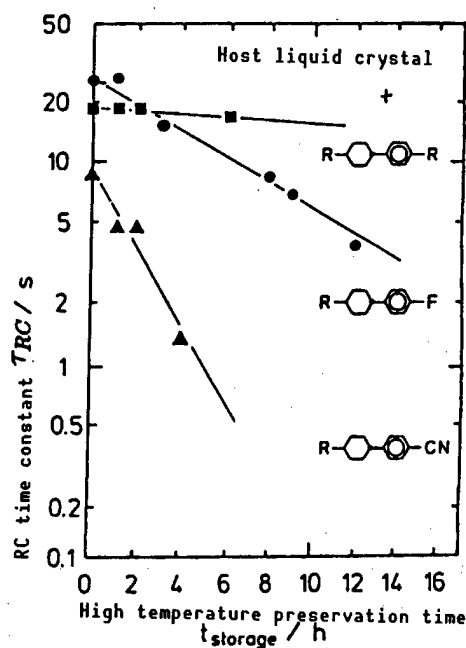


Figure 8. High Temperature Preservation Characteristic of Liquid Crystal Material

6. Future of Liquid Crystal Materials

It would appear that, in the future, LCDs are going to become larger in display volume, image size, and precision, and will enjoy multifarious development centered around the active matrix LCD, then progressing to TN, STN, ECB, and ferroelectric LCDs in simple matrix LCDs as well. Under these

conditions, fluorinated liquid crystal materials represented by DFS and SFM possess diverse characteristics capable of coping with LCDs of all operating modes, together with enabling extremely varied structures to be realized. Moreover, it has illuminated the point that the realization of low viscosity can also improve display speed, which is one of the defects of the LCD. Furthermore, expectations are great for fluorinated liquid crystal materials due to their conspicuous stability, as well as for their expansion to vehicle loading and aircraft applications, that are indispensable as practical application expansions of LCDs. Great expectations are harbored in the development of fluorinated liquid crystal materials of other structures, and that they will contribute to the development of LCD displays by fully exhibiting their characteristics.

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