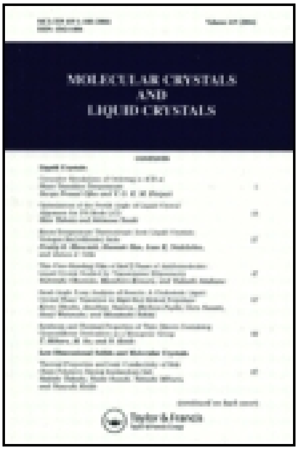

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LCD Developments Leading to HDTV

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LCD Developments Leading to HDTV

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LCD technologies, in particular active-matrix LCDs, will take another giant step in the 90's towards laptop computers and high-definition TVs (HDTVs). Since HDTV provides the clear images with much higher resolution than the currently available TV images, larger screen size, at least 40″, is needed.

In order to attain the direct-view LCDs for HDTV, some fundamental problems must be solved. The most serious problem may be enormously high production cost. Therefore, such an approach will need a long term effort before practical use. Projection displays with LC light-valves are a more realistic way for HDTV. In this method, higher contrast ratio and resolution LCLVs and bright light sources with long life are the key issues. In the next three years, practical HDTV LC projectors of either rear or front projection may appear.

1. LCD EVOLUTION AND CURRENT SITUATION

The liquid-crystal displays (LCDs), which were born in the late 1960's, have recently taken giant steps toward use in large area flat display panels. In the initial stage of practical applications, small size LCDs with only a few tens of pixels, as shown in Figure 1, were applied to the watch and hand calculator displays. The twisted-nematic LC mode[1] was used instead of the previously created dynamic-scattering mode (DSM).[2] Since then, dot-matrix displays with multiplexed scanning signals have arisen targeting larger information content and have advanced by two driving techniques: passive matrix[3] and active matrix.[4]

Until the mid 80's, and still now in specific application fields, passive matrix LCDs have been the dominant technology in dot-matrix LCDs. Initially, multiplexed TN had been used, but as the matrix size grew, this method developed serious limitations in contrast ratio and viewing angle at around a scanning duty of 100. Then, the appearance of the supertwisted-birefringence effect (SBE)[5] and supertwisted-nematic (STN) modes[6] drastically reduced the barrier enabling progress toward CRT-like displays.

The active-matrix approach has been an alternative technique to passive matrix in the dot-matrix configuration for large information content LCDs. This technology was created in the late 60's,[7] but due to poor production techniques of active elements, practical application started only in the 80's with polycrystallized and amorphous Si thin-film transistors (TFTs). Great breakthroughs for a full color display were achieved with the active-matrix LCDs which made LCDs the most

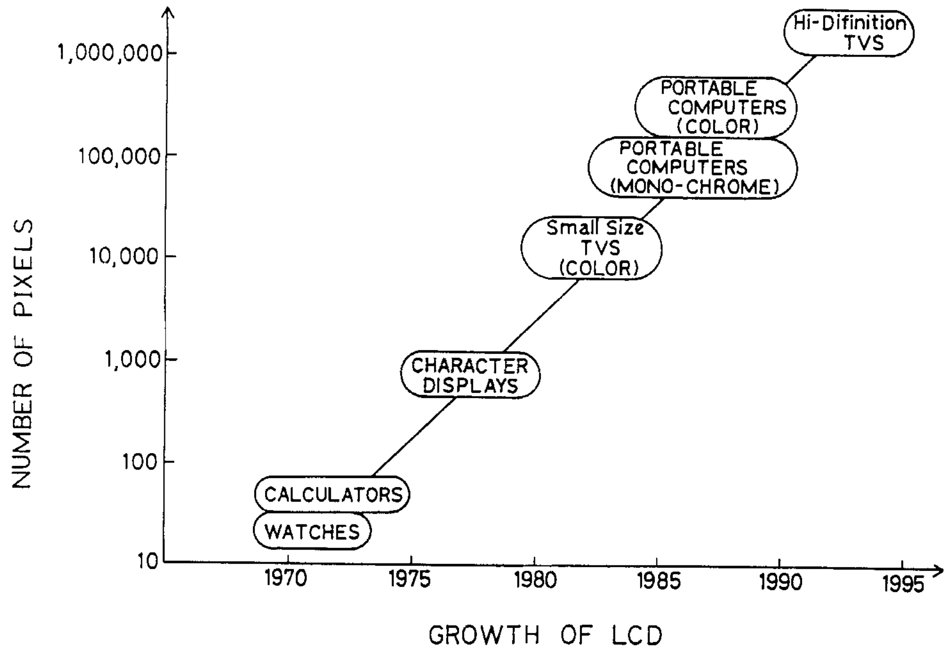

FIGURE 1 LCD progress in number of pixels. HDTV requires a few million pixels.

promising technology of the flat panel display devices. The display size of active LCDs which used to be small because of difficulty in active-element fabrication has been enlarged to sizes comparable with that of CRTs by progress in manufacturing techniques.

Thus, LCD technologies have been considerably advanced by improving display and matrix size as well as viewing capability which is defined by contrast ratio, viewing angle, response speed, and chromaticity. Such advancement led LCDs from a minor to a major player in electronic devices, generating a large amount of business investment, eventually targeting replacement of CRTs in the distant future. LCD applications are an important issue in order to achieve this role. Currently, LCDs have two main application fields: video image displays and data images for computers. These are significant driving forces in LCD developments. Since laptop computers in the computer market are growing so rapidly, flat panel requirements for them have become very strong. Therefore, LCDs are taking a major part in this area. In video display devices, LCDs are also forming an important role in sizes both smaller and larger than that of currently available CRTs, the recently-appeared high-definition TV (HDTV) requires larger size displays for home installation in which CRTs cannot be used. LCDs have a high potential for use in HDTV.

2. ACTIVE-MATRIX APPROACHES FOR VIDEO IMAGE DISPLAYS

As mentioned before, LCDs have a high market potential in computer and TV applications. (Figure 2) In these applications, both passive and active-matrix LCDs

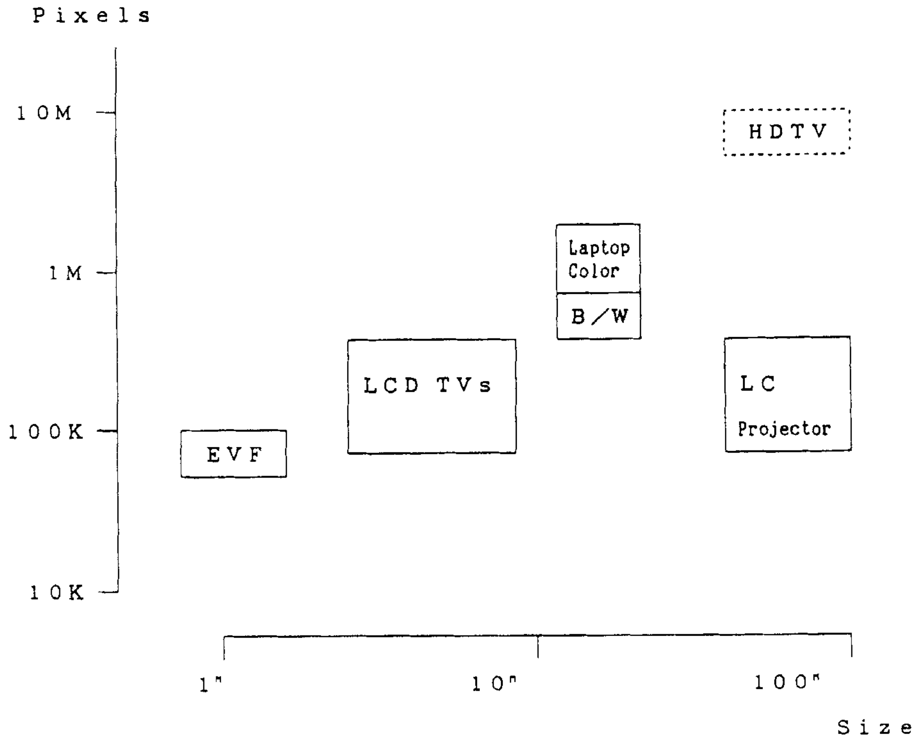

FIGURE 2 LCD applications in sizes v.s. pixel numbers. EVF stands for electric view-finder for video-cameras. 10″ displays for laptop computers are major application.

have been used. Since the passive LCDs, especially STN and neutralized STN with retardation LC cells[8] or films[9] for color compensation, can realize a lower cost due to their simple structure, they have been applied to laptop computers and related products which incorporate monochrome displays at approximately 10-inch diagonal size. However, the need for color displays for these applications is increasing. Although both neutralized STN[10] and active-matrix have color capability, the active-matrix approach may have higher potential in the future because color quality is the key in color displays.

Such color quality is more important in video displays since the same or better color image quality than that of CRTs is required. From this point of view, the active-matrix LCDs have been taking and will continue to take a major role in video display applications such as TVs.[11] The practical active-matrix LCD started with 2″ diagonal color displays with a poly-Si TFT array.[12] Since then, the display size has been enlarged up to 14″[13] in laboratory-made displays. For TV sets, up to 6″ display size is currently available. The next target of the active-matrix LCDs is 10″ color displays for laptop computers.[14,15] Thus, active-matrix display size will advance with progress in manufacturing techniques including equipment and related materials.

In the past, various kinds of active elements have been developed. At the moment Si TFTs with amorphous[16,17] and polycrystallized[18] films and thin-film diodes with a MIM (metal-insulator-metal) structure[19] are commercially available. Figure 3 shows applications of these active elements. Relatively small size displays of less than 3″ diagonal have been using poly-Si TFTs taking advantage of high mobility which allows high pixel density and driver circuit integration. These LCDs have over 70,000 pixels and have been applied to color view finders for home video cameras and projection light valves. Since amorphous Si TFTs have large area capability due to low temperature fabrication at less than 350°C, they are suitable for larger size displays. Presently, color 3″–6″ diagonal displays with 80,000–120,000 pixels are commercially supplied for pocketable/portable LC-TVs and portable VCRs. Soon, 10″ color LCDs with amorphous Si TFT arrays of 480 × 640 color triodes incorporated into laptop computers will appear. MIM thin-film diodes are being used in similar applications to those of amorphous Si TFTs.

These three types of active elements are compared in Table I. Amorphous and poly-Si TFTs are suitable for realization of excellent color image quality since they have on/off current ratios as high as 10^7 which are higher than those of thin-film diodes. (Here, the on/off current ratio stands for switching performance by the active element with a higher value corresponding to more ideal operation.)[20] Si-

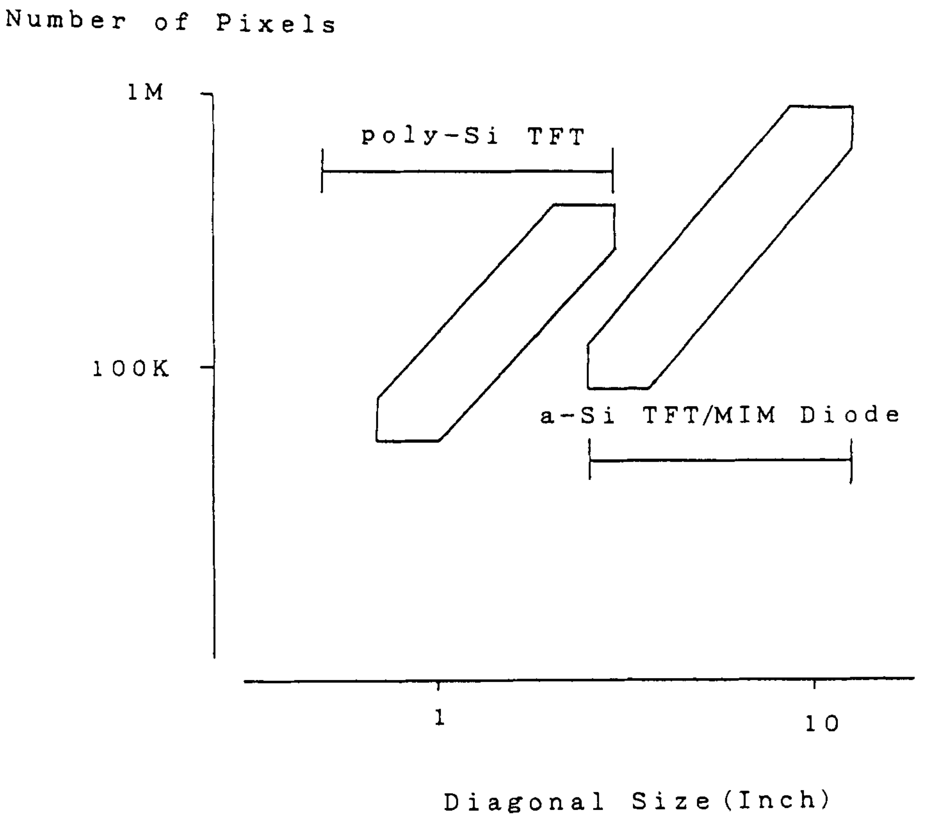

FIGURE 3 Active-matrix LCDs segmented by elements. Poly-Si TFTs have been used for smaller size.

TABLE I

Comparison of the active elements. Amorphous-Si TFTs and MIM diodes can be fabricated on the large size glass. Poly-Si TFT can incorporate the driver circuits on the glass though they require higher fabrication temperature

	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
Grey scale	16~32	>16	>16

multaneously, amorphous Si TFTs and thin film diodes have high potentiality for large substrate and display size because of sufficiently low temperature fabrication. MIM diodes have the highest potential with respect to cost due to the simplest fabrication process.

In any active element choice, cost and image quality must be considered. Since video displays, in particular HDTV displays, always require excellent color images, as good as that of CRTs, and price as low as that of CRTs, TFT arrays give the best image quality but are also costly. Diode arrays are cost effective, but need further improvement to achieve a much higher on/off current ratio.

3. HDTV REQUIREMENT FOR LCDs

Recently, the screen size of home TV is increasing. As a result, 30″ CRTs for direct view or 40″ projection screens with CRT image sources have become quite common for watching TV programs. Also, by the wide-spread use of VCRs, movies can be easily enjoyed instead of going out to a movie theater. However, as such screen size increases, picture resolution with present standards has become seriously reduced if we keep the same distance from the screen. Therefore, demands for larger size screens with higher resolution are rapidly growing. High-definition TV (HDTV) has appeared to satisfy such requirements.

High-definition TV (HDTV) implies super resolution TVs compared to the currently available TV standards such as NTSC, PAL and SECAM which have 350–500 TV-line resolution horizontally and 525 and 625 scanning lines for NTSC and

PAL/SECAM, respectively. Until today there has been various proposals for high-definition TV standards. Most of them aim at over 4 times higher resolution than current standards, for example with a little more than 1,000 scanning lines and 1200 horizontal TV-line resolution.

Typical requirements for HDTV displays by LCD technologies are summarized in Table II. Display size must be larger than 40-inch diagonal. This size might be beyond CRT capability for home use from the view point of physical dimensions and weight. This is the reason why flat panel displays are necessary for HDTV displays. Resolution of HDTV demands about $1{,}000 \times 1{,}500$ color triodes, i.e. $1{,}000 \times 4{,}500$ pixels, for LCDs. Brightness is another key issue for clear color images. Present 36″ CRTs which were developed to meet HDTV requirements have good resolution but poor brightness lower than 100 ft.L because of current limitations in the electron gun and a shadow mask that is too small. Screen brightness of 300 ft.L is reasonably necessary. However, in the case of LCDs, viewing angle dependency may degrade image excellence, so this matter must be carefully considered. Although required physical size has no clear limitation for home use, less than 30-inch in depth and 30 kgs in weight are reasonable.

4. TWO LCD APPROACHES TO HDTV DISPLAYS

There have been two methods for CRTs with respect to realization of large size displays. They are direct-view and projection. Likewise, presently two approaches: direct-view, very large size LCDs and projection displays with liquid-crystal light-valve (LCLV) technologies have been taken for HDTV displays.

The comparison between the two are shown in Table III. Direct-view LCDs may achieve a higher image quality than projection displays, which is the same situation between direct-view CRTs and CRT projectors. Therefore, true "hang-on-wall TV" will be achieved by direct-view LCDs. However, the fabrication of these

TABLE II

Requirements for HDTV displays. Size and resolution are first priority in HDTV displays

1.Screen Performance	
	*Display Size
	*Resolution
	*Brightness
	*Viewing Angle Dependency
2.Physical Requirement	
	*Dimension
	*Weight

TABLE III

Advantage comparison between direct-view and projection HDTV displays. Projection approach is more realistic than direct-view

	Advantage	Disadvantage
Direct-View	Space Saving Excellent Image	Difficult to Fabricate Expensive
Projection	Easy to Realize Cost Effective	Image Degradation Relatively Big

LCDs which meet the HDTV requirements described above are very difficult to obtain at present. Even though such fabrication is possible today, no doubt the price of such TVs is extremely expensive. Accordingly, projection displays are more realistic than direct-view though their image is somewhat degraded compared to that of direct-view. They have relatively large physical dimensions, but they are still smaller than CRT approaches and thereby allow home installation.

5. POSSIBILITY OF DIRECT-VIEW 40″ ACTIVE-MATRIX LCDs

Over 40″ diagonal TV displays with direct-view LCDs by active-matrix technology have not been achieved yet because of fundamental limitations in their fabrication. Furthermore, in order to achieve HDTV displays which have very beautiful and clear pictures, there are additional problems. Such limitations and problems can be divided into four factors: size, viewability, power, and cost. They will be discussed as follows.

5.1. Size

The size problem results from two limitations: active element fabrication and liquid-crystal cell assembly. Figure 4 shows the size progress of the active matrix LCDs. 2″ diagonal was the starting size and presently 10″ is the maximum practical size. Laboratory size will reach 20″ soon. Thus, the active-matrix LCD size has been enlarged and in the future 40″ size can be expected during 1995–2000.

At the moment, maximum size in active-element fabrication is limited by the manufacturing equipment, especially photolithography machines that form micro patterns on the glass substrate. Usually, projection patterning, which can eliminate the defects caused by contact between the photomask and the glass substrate, is employed. Due to the difficulty of one time projection exposure, the step and

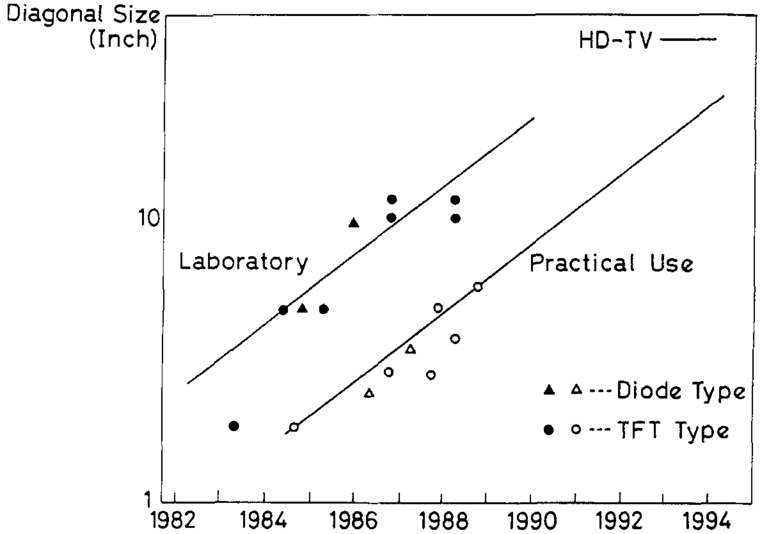

FIGURE 4 Size progress of the active-matrix LCDs. At the moment, 14″ is the maximum size, though HDTV requires more than 40″.

repeat method, in which exposed size is limited, is necessary. Up to 60 cm × 60 cm substrate exposure may be achievable in the future, however realization of 1 m size, which is essential for 40″ displays is unclear.

Cell assembly is another size limitation. In the case where TN mode is employed, strict cell space control is adequate. But, stress generated by weight of the glass substrate and the liquid-crystal material may prevent cell space uniformity. In order to avoid such problems, very thick glass may be required. At the same time, uniform liquid-crystal injection into the vacant cell may become very difficult. Consequently, conventional cell assembling techniques cannot be applied to the 40″ size LCDs; and, therefore new assembling methods must be developed.

5.2. Viewability

Twisted-nematic (TN) mode which has been dominantly used in LCDs has two limitations in principle: dynamic range in electro-optical response and viewing angle dependency. Dynamic range, which corresponds to optical transmission property with respect to the applied voltage, may determine chromaticity as well as the total contrast ratio, and grey scale reproduction. Since such property has saturation regions in both black and white states unlike CRTs, grey scale capability and contrast has a trade-off relation. If TN has a contrast ratio as high as 1,000, such a problem may be eliminated. But, in fact, the present contrast ratio of TN mode is limited to less than 300. Smooth grey scale reproduction with high contrast is an essential factor for high quality color video images.

Optical response variation to the viewing angle is another serious problem in TN. As the display screen size is enlarged, human eyes catch the image from more various angles. In this case, the image must be the same for all angles. Therefore, some idea such as eliminating such dependency by another optical plate to cancel the angle dependency is required. Otherwise a new liquid-crystal mode without polarizers, instead of TN, may be necessary.

5.3. Power Dissipation

Present color LCDs employ the additive color production method with a mosaic RGB color filter layer incorporated into the liquid-crystal cell. In order to produce high chromaticity, light transmission through the color filter is degraded. The typical transmission of white light through presently available color filters is 15%. If such color filters are combined with active-matrix cells employing TN mode, total transmission is drastically lowered to 3–5% due to absorption by polarizers, low aperture ratio of the active substrate and reflection at the optical interface. If 300 ft.L is necessary, as mentioned above, more than 1 kW backlight power may be required. Such a system is impossible to hang on a wall. Therefore, a new idea which allows high transmission, instead of TN or different color production techniques, must be created.

5.4. Cost

Cost is the most serious problem in the large size active-matrix LCDs.[21] Since such LCD production needs similar equipment and machines to those of semiconductor devices, investment to establish a production facility becomes very high. Certainly production yield is a problem. But even though at a high yield, depreciation derived from such investment is fairly high. In order to avoid this problem, throughput which is defined by machine capacity per hour, must be improved. Otherwise, a cost reduction approach through the active element itself is necessary. Here, we have three choices among structure and associated process simplification of amorphous Si TFT, driver circuit incorporation by poly-Si TFTs with mobility improvement, and employment of diodes with on/off current ratio improvement.

Subsequently, realization of 40″ direct-view active-matrix LCDs will take a long time in research and development of the liquid-crystal color display mode and method, and active-element structure and fabrication process as well as production equipment and related materials.

6. HDTV PROJECTION DISPLAYS WITH LIQUID-CRYSTAL LIGHT-VALVES

As mentioned above, liquid-crystal projection displays are a more realistic approach than the direct-view method for HDTV displays. There have been several techniques for LC light valves. As a classical but promising light-valve, a spatial light modulator by combination of liquid-crystal and photoconductive layers has been applied to high resolution projection color displays.[22] The color image is transferred from three CRTs which are assigned to the RGB beams of the photoconductive layer of the corresponding LC light-valves. However, it is unknown whether this method can be applied to home use because the size and weight of present systems are too great.

The most active method for consumer TV or HDTV projection displays with liquid-crystal light-valves (LCLVs)[23,24,25] is the employment of active-matrix LC cells with TFT arrays. Three red (R), green (G), and blue (B) beams which are separated from a white light source, are synthesized on the screen after light modulation by the corresponding TFT-LCLVs.

As an application set, rear and front type projectors are available as shown Figuré 5. Although front types always require a dark environment to enjoy clear pictures, they can easily realize a large size screen for HDTV with truly compact and light weight, set appropriate for home use. On the other hand, rear types may generate an relatively clear image compared to front types. Since they require appropriate space to incorporate projection functions in the box, volume and weight must be larger than those of front types, however such values are still much smaller compared to HDTV CRT rear-projectors. Thus, both technologies, front and rear types, are available for HDTV screens.

The optical configuration of LC projectors which have been applied to the front type projectors are shown in Figures 6 and 7. The dichroic mirror scheme for color

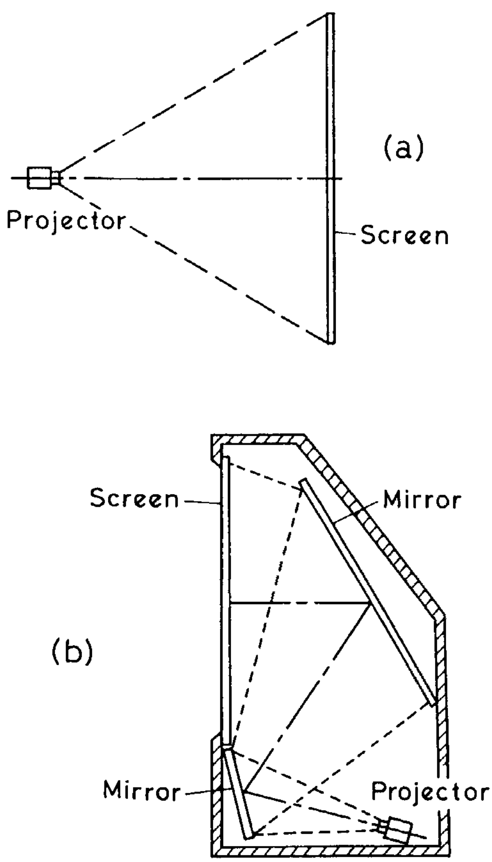

FIGURE 5 Configuration of projection display with liquid-crystal light-valves. Both rear and front projection are available.

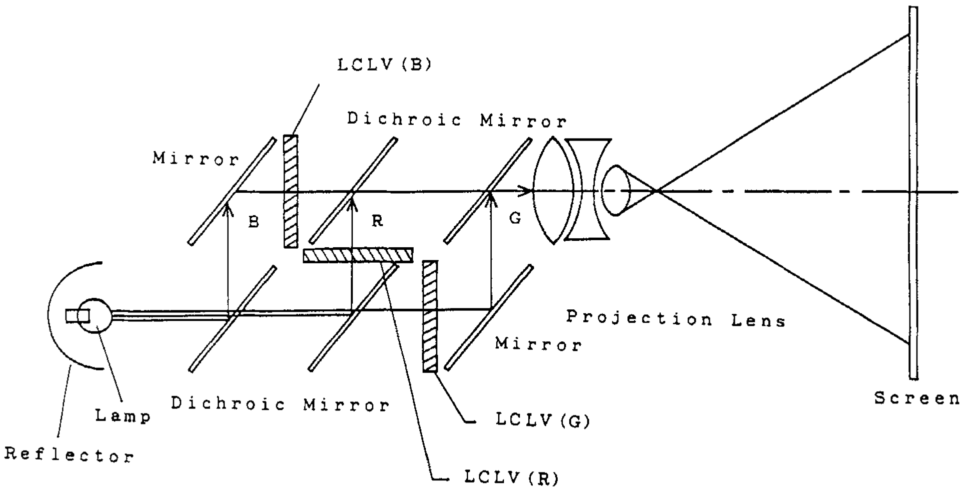

FIGURE 6 Optical configuration of LC front-projector with dichroic mirrors for color separation and color synthesis.

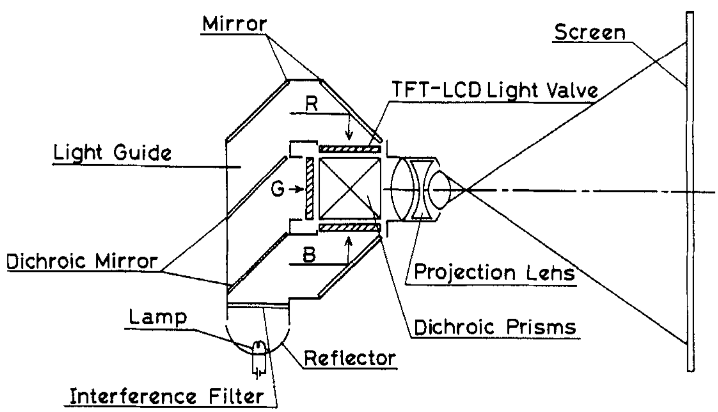

FIGURE 7 Optical configuration of LC front-projector with dichroic mirrors for color separation and dichroic prism for color synthesis.

synthesis shown in Figure 6 can achieve a high screen uniformity with respect to color and brightness due to the equal distances from the light source to the light-valves and from the light-valves to the projection lens between the three beams. Subsequently it can be applied to relatively large size light-valves. However, the long distance between the projection lens and the light-valves simultaneously requires a large radius lens with long backfocus length, resulting in high cost. A dichroic prism scheme (Figure 7) was created to make the set more compact by minimization of lens-lightvalve length. Although it has a drawback in that screen uniformity is slightly degraded because of the difference in distance between light source and light-valves, smaller size LC light-valves is effective for this method.

A configuration example of rear-type projection TV with LC light-valves[26] is shown in Figure 8. It consists of one light source, a beam separator, three transmissive LC light-valves, and not one, but three projection lens. Since in rear-types and lens-screen distance is always constant, this makes such distance small.

In such configurations mentioned above, LC light-valves employ a liquid-crystal cell with TFT array as shown in Figure 9. Both poly-Si and amorphous Si TFT, and TN liquid-crystal mode with transmissive type have been applied to the LCLVs. They have a light-shield layer over TFT elements and space between the pixels and metallization in order to eliminate light-leakage through the electrically un-

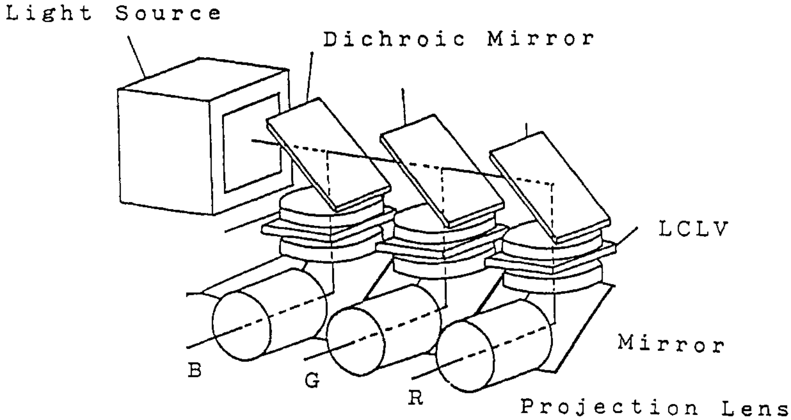

FIGURE 8 Configuration of rear-projector. Three projection lenses for corresponding color beams are employed for color synthesis on the screen.

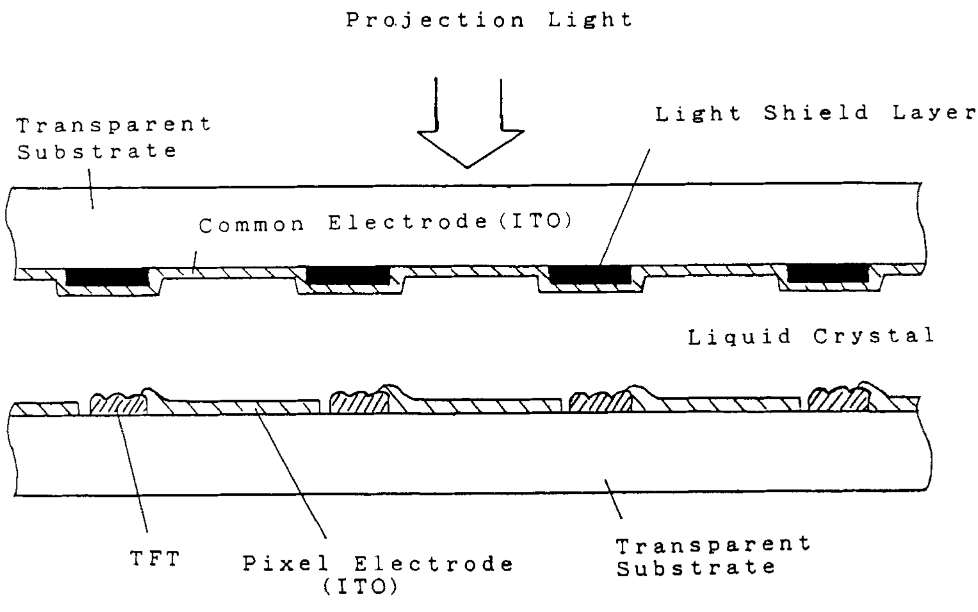

FIGURE 9 Cross-section of active-matrix LC light-valve with TFT array. Light-shield layer is applied over the TFT area and gaps between pixel electrodes.

controllable region and to enhance the contrast ratio. However light-transmission of such light-valves is low due to the polarizers required for TN mode and the small aperture-ratio resulting from the light-shield layer. For example, of currently available active LCLVs, the aperture ratio of 3″ LCLVs with amorphous Si TFT arrays which have 240 × 378 pixels is about 50%. A 40% aperture ratio was realized with a poly-Si TFT array of 220 × 320 pixels in 1.3″. Such a value resulted in as low as less than 15% light transmission of the LC light-valves. In order to improve such low transmission, reflective LC light-valves were developed by the combination with ECB mode.[27] The use of aluminum pixel electrodes instead of ITO (indium-tin-oxide) for transmissive type, achieved an excellent aperture ratio as high as 70% though contrast ratio was degraded due to the ECB mode.

The light source is another key component other than LC light-valves. So far, metal-halide, xenon, and halogen lamps have been tested. The comparison between them is shown in Table IV. Here, since projection optics necessarily require close to parallel light flux, closer point light source contributes higher light collection efficiency. Although light collection efficiency of xenon lamps is the highest, life time and cost, including ballast circuits, are serious problems. Since halogen lamps can easily be used because of low cost, they have been used for practical use, but lifetime and color temperature are still problems. Metal-halide lamps are the best for video picture applications due to high light emission efficiency and high color temperature though they are not ideal.

Screen brightness is one of the keys to obtaining clear images as pointed out previously. Such brightness is improved by the light source, light-valves, and total optical design. At the moment, light which reaches the screen is less than 1% of the total emitted light from the light source. In such a case light collection efficiency from the light source is about 10%, transmission of the light-valves is about 15%, and other optical loss is 50%. In order to improve light efficiency of the light source, efforts are being made to shrink the arc length to collect more light flux, keeping its lifetime longer than 6,000 hours. Still, currently only 10% is incident on the light-valves. Therefore, a higher efficiency light source with pretty close to point-emission is required. Present light-transmission is very low. Elimination of

TABLE IV

Light sources possibly employed in LC projection displays. Metal-halide lamps have the highest potential from the view point of light efficiency, color temperature and life time

	Conversion Efficiency (lm/w)	Light Collection (%)	Color Temperature (°k)	Lifetime (Hours)
Metal-Halide	80	15	6000	2000
Xenon	30	25	6500	500
Halogen	30	10	3200	100

polarizers is very effective as well as employment of the reflective mode or improvement of the aperture ratio. From this point of view, polymer dispersed liquid-crystal (PDLC) is a new approach,[28] in which optical transmission is improved more than two times by electrically controlling transmission from transparent to scattering state.

The LC projection HDTVs demonstrated for the first time last year are exhibited in Table V. Rear-type[29] employed reflective LC light-valves with 960 × 1422 amorphous Si TFT array in 2.3″ diagonal size. Although their aperture ratio is as high as 70%, contrast ratio must be improved. The optical configuration of front-type[30] uses conventional method. LC light-valves adopted 1,000 × 1,200 amorphous Si TFT array in 5.5″ for transmissive mode. Screen brightnesses are 30 ft.L and 50 ft.L in 40″ of rear projection and 110″ of front projection, respectively. The brightness as well as the contrast ratio are much lower than the requirements as pointed out in Table II.

TABLE V

HDTV LC projection displays presented so far. Both rear- and front-types have developed. Their resolutions are sufficiently high to meet HDTV pictures

Company	Matsushita	Sharp
Type	Rear	Front
Optics		
Light Source	250w Metal-Halid	Metal-Halide
Color Separation	Dichroic Mirror	Dichroic Mirror
Color Synthesis	Post Lens	Dichroic Mirror
Projection Lens	3 Lenses	Single Lens
LC Light-Valve	(Reflective)	(Transmissive)
Elements	a-Si TFT	a-Si TFT
Pixels	960x1422	1000x1200
Size	2.3"	5.5"
Aperture Ratio	70%	
Driver LSI	External	External
Image		
Brightness	30ft.L	50ft.L
Contrast	30:1	100:1
Screen Size	40"	110"
Set		
Weight	50kg	
Volume	97x85x45(cm3)	

7. CONCLUSION

Liquid-crystal developments leading to high definition TVs (HDTVs) have already started. In the age of HDTVs which require higher resolution in larger screen size, conventional cathode-ray tubes (CRTs) may not meet HDTV requirements. Instead, LCDs may be dominant in this application field. Both approaches, direct-view and projection, are candidates for potential technologies.

Although direct-view LCDs can achieve a true so-called "hang-on-wall" television set, its realization will take a long time. At the present time active-matrix technology may have the highest potential for HDTV because it allows the highest image quality. However further fundamental investigations are necessary to develop the most suitable liquid-crystal mode, most productive active elements as well as manufacturing techniques, production system including equipment, and related materials.

Projection displays with liquid-crystal light-valves are a more realistic way than direct-view for realizing the HDTV displays soon. There have been two methods: rear and front projection. Front-types can compact the completed set and are suitable for larger screens, but a dark environment is always required. Since weight and depth of rear-type boxes are smaller than those of CRT projectors, they have high potential for quasi "hang-on-wall TV". Both types employ active-matrix LC light-valves for excellent quality images as well as direct-view LCDs. In order to achieve required screen brightness, a light source with high efficiency and simultaneously long lifetime must be developed. Light transmission of light-valves must also be improved as well as the contrast ratio.

As a result of such development efforts, the days when most TV displays employ liquid-crystal technologies may come in the distant future with the application areas classified as smaller screen size (up to 40″) by direct-view, medium size (40″–70″) by rear-type projection, and larger size (more than 70″) by front projectors.

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