Recent Trend of Display Devices

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Abstract

A trend of recent R & D on display devices, especially flat panel display, are reviewed. In addition, historical growing process of liquid crystal display (LCD) is reviewed from both sides of a simple matrix LCD technology and an active matrix LCD technology, and a trend of recent advanced technology is also discussed.

Introduction

Starting with the sub-micron-level super-micro processing technology, the high-performance Si-LSI technology has created an advanced information society based on electronics devices. To make full use of these devices, a remarkable progress was made in software technologies in computing and communication categories. The combination of the processing and software technologies is achieving another new information society, where communication systems unite digital-oriented multimedia information as one global network.

This new trend could compete the time when Gutenberg's invention of printing technology in the 15th century, from the view of our cultural history. This will make its name in the history as Gutenberg's invention did.

The new society mentioned here is a new information society where digital electronics has begun to exist in our human-oriented society and both have been integrated into one. It is not only human beings that compose the new information society, but also objects such as phenomenon and society, input devices, information (signal) processor, memory, transmission, and output (display) equipments.

The display equipment as an output device bridges information between electronics devices and human beings. In other words, it has an essential feature different from that of other memory or information processing devices in a way that the display equipment performs as a man-machine interface, interpreting digital information signals for us. We believe that because the display is meant for human beings, it needs to have some human-like characteristics to be a man-machine interface.

Because of these unique features, the display equipment has made its own technological and economical progress in terms of the mechanical development, which should be noted for the future discussion.
One example to show the display equipment's uniqueness is a "Display size as a device dimension" issue. There is a limit for the size, depending on the device's capability and the visibility from human eyes' resolution, and the limit also relies on the distance of light in which the device is used. Further, the display equipment's outer design strategically has important meanings when we look at the product concept, because it can be a face itself for all the electronics products. On the other hand, the dimensions are related not only to quantity manufactured in production line but also to the cost. Thus, the display devices cannot be ignored in the respects of business strategies and management. All this shows how unique the display devices are, compared with LSIs, which need to be as small in size as possible in order to perform high-speed processing and excellent productivity, while higher-capacity of LSIs are preferred for memory or information processing devices.

This paper explores how the display devices are developing and will develop, introducing liquid crystal display techniques such as a flat panel display, which will replace the CRT as a basic device.

1. Recent Trend of Display Technology

The year of 1997 is the 100th year since Braun invented the CRT as a display device. In the drastically changing electronics world, no other technology in this display field has never existed such a long time as the CRT has. As mentioned in the **Table 1**, new display technologies have been introduced based on various operating principles for these past 100 years, but no devices are yet to come in its business scale.
Now that the LCD has been made into use for 25 years, it is competing the CRT in the market share with its strength of compatibility with digital multimedia technologies. In the technology field of large-screen panel, the PDP's progress cannot be ignored, either. In addition, other new technologies such as another new flat panel display FED and an organic EL will be

Table 1 Display technologies and they're operating principles

Display Method	Operating Principles
CRT	Utilization of light emission caused when fluorescent substance is activated by high-speed electron beam.
VFD	Utilization of light emission caused when fluorescent substance is activated by low-velocity electron beam.
FED	Utilization of light emission when accelerating emission of field electron activates fluorescent substance.
LED	Utilization of light emission when re-coupling of hole carrier and electron occurs.
PDP	Utilization of light emission when phosphor is activated by ultraviolet from gas-emission.
EL	Utilization of light emission caused by ionic collision and re-coupling has accelerated electrons within a solid body.
LCD	Utilization of the optical effect based on alignment deformation of liquid crystal molecules through electric
DMD	Utilization of optical route change caused by micro-mirror deviation through electric fields.
ECD	Utilization of the chromatic reaction effect caused by electronic chemical reaction.
EPD	Utilization of the cataphoresis effects of chromatic grains.
MPD	Utilization of rotation caused by chromatic magnetic grains in the magnetic domains.
MOD	Utilization of optical deviation by the magneto-optic effect.

introduced soon if the problems on device structures and materials are solved.

This section reviews the prospective for the recent trend of these new display devices, and in the next section the trend of the LCD as post-CRT will be explored.

1·1 CRT

The CRT established its rigid status as a high-performance and cost-effective digital device and it was made into use for TVs and PC monitors. However, the CRT will be soon confronting the limits of performance due to restriction of its limited screen size (max. approximately 40 inches), capacity and consumption power.

To make further improvement on the CRT, the recent technological trend shows that a lot of efforts are devoted in order to allow the displays to be larger in size, to be more high-definition and flat-face, to enhance its color purity, and to low power consumption.

For example, the 36-inch wide large display for TV use has now been mass-produced for the market, and for the CAD monitor, the 24-inch 16:10 wide high-definition tube and the 28-inch high-definition super-flat type has also been in a process of development and production with the aperture-grille method. 'Flat face' is becoming a main trend not only in PC applications but also in TV applications and this trend is changing the conventional image of the CRT. Flat-faced TVs look like an FDP at one glance of the screen. Size reduction of the neck diameters and improvement of electron guns has enabled the power consumption to be improved by 30%, compared with that of the conventional. For higher contrast and more enhanced color purity, color filters are applied to the fluorescent substance and this kind of approaches have been made in order to reduce/prevent the reflection on the face plate, contributing to higher display performance.

It is less likely to break through CRT's limited performance in size. Instead, it will remain to be one of the display commodities with more improvement by taking advantage of its cost-effectiveness.

1·2 PDP

The 40~50-inch large PDP is making a remarkable progress for the past few years after the introduction of a new structure, applied an AC-type normal discharging method using MgO as cathode material and electro-protecting film with the fluorescent substance on the rear. The PDP for the 42-inch NTSC-TVs is starting to be manufactured in small quantity, with an aim to realize the high resolution in the NTSC (852 x 480 pixels) and in the digital ATV (1280 x 720 pixel, 1920 x 1080 pixel). The PDP is brightness; luminous efficiency and lifetime are also focused. Although

a large amount of plant investment is being made by some companies looking at the possibility of the next-generation TV mass-production, a lot of preliminary challenges remain to be overcome, such as its poor color and outline reproduction, and cost-performance for consumer equipment.
A lot of R&D projects and plant investment are now on their way in order to solve these problems and eventually to realize the mass-production of the PDP.

1·3 FED (Field Emission Display)

The FED, one of the flat CRTs, has a field-emission electron beam that corresponds each pixel. Although the FED was launched more than 20 years ago, it has not gone into the market yet due to the scant electron emitter and fluorescent substance, both of which are required to realize the stable display with high brightness.
It was once suggested that the resistant layer be inserted into the FED emitter or that the buffer transistor on the silicon substrate be combined with the FED emitter. However, this has not solved the problems due to the trade-off for the display brightness and size.
Recently has a new suggestion of the on-surface transmission emitter method emerged, which is meant to increase the FED's size larger than the 40-inch PDP. This method is under its development with a 3.1-inch prototype (240 x 3 x 80 dots). Although it still needs more improvement in the lifetime and uniformity, the method is drawing the attention from the researchers because of its high mass-productivity. For the past few years since the American government established a specialized consortium, positive efforts have been made on the development of a new type of fluorescent substance suitable for the FED. Despite these constant efforts, we have not come up with any determining solutions yet, and we need to work on further breakthroughs for the FED development as well as for the emitter development.

1·4 EL

Studied from the display principle view, the EL is classified into an inorganic EL and an organic EL, both of which are intended to achieve a full-color FPD. At the same time, they are designed to play a different role from other kinds of FPDs in the medium-/small-size high-definition display field, taking advantage of their strength such as long life and wide range of operating temperature.

In the inorganic EL field, multi-colorization was realized thanks to the development of new $CaGa_2S_4$: Ce high-efficiency blue material and the layer structure of ZnS-oriented material such as red and green. The highly reliable white EL (SrS:Ce/ZnS:Mn) layer and the color filter are combined together, which made possible the simple structure and enhanced high contrast, and this new combination of the two will soon be taken into practice for industrial equipment applications. Led by the United States, the thin film EL is being developed for more advanced applications. For example, the primary level of super-high-definition HMD (Head Mounted Display) is developed with the silicon MOS technology for military use.

There is a trend notable when we look at the organic EL field. That is, practical devices with the organic EL have been increasingly focused for 10 years since the development of double-layered structure of light emission and hole transmission. A full-color display is one example for a possible EL device. There are now 2 reliable different approaches for this: one is the combination of a white-light emission layer and a color filter, and the other is the combination of a blue-light emission layer and red and green fluorescent layers.
However, the EL still has much to be improved. For instance, high-efficiency red material needs to be developed in order to enhance colorimetric purity and also the molecular lifetime needs to be prolonged. Thus, further material and structural breakthroughs are required in order to realize a full-color EL display.

1·5 Other Display Technologies

The DMD (Digital Micromirror Device) is one of the distinctive technologies besides the above mentioned. The DMD is a space light modulator element, which was developed combining the Si-LSI technology of the Texas Instruments Corporation and the micro-machine technology.

The DMD modulates light, moving the microscopic Al reflection mirror by the electrostatic field to change the direction of light reflection. Although the DMD used to have a problem with wear and tear in the metallic tray of micro-mirror axis, the optimal solution has been made and the DMD now comes into practical use for projector applications.

In addition, another strength about the DMD is its high-speed response (several microseconds). Making use of this feature, the DMD is developed and merchandised as a single-panel projector with a time-sequential drive, which even can compete the liquid crystal projector.

2. Trend of the Liquid Crystal Display (LCD) Technology

The real mass-production and utilization of LCD was done by SHARP in 1973. The first LCD was used for a compact display for numbers on a portable electronic calculator. Now the LCD represents the FPD technology and it is highly noted as a main display technology for the next generation, which could replace the CRT.
In this chapter, the LCD's progress in the past is reviewed and the prospective breakthroughs for the recent technological blocking.

2·1 LCD's Historical Progress

The **Table 2** shows the LCD's Historical Progress.
Here, some of the remarkable episodes will be reviewed.

Table 2 Historical chart of the LCDs.

Year	History
1888	Reinizer discovers liquid crystal.
1920's	Friedel identifies liquid crystal as intermediate-phase reaction.
1930's	Marconi (England) applies for a patent in order to utilize liquid crystal.
1960's	WH (USA) and RCA (USA) start to research LCD
1963	Williams (RCA, USA) releases a paper on LC's elecro-optical reaction.
1968	RCA develops the first LCD prototype (digital clock) with use of DSM (Digital Scattering Mode) and releases a paper.
1969	Hoechst (Germany) releases a paper on composition of a room temperature LC (MBBA).
1971	Roche (Switzerland) develops a TN mode and releases a paper.
1973	SHARP (Japan) mass-produces and practicalizes the world's first calculator EL805 with an LCD.
1979	Spear and et al. from Dundee University (England) develop a prototype of a-Si color TFT-LC TV and release a paper.
1982	Suwa Seiko (Japan) develops a high-temperature p-Si color TFT-LC TV.
1985	Sheffer and et al., BBC (Switzerland) develop a prototype of STN-LCD and release a paper.
1986	Matsushita (Japan) merchandises a color LC-TV with a-Si TFT-LCD (NB method).
1987	SHARP (Japan) merchandises a color LC-TV with a-Si TFT-LCD (NW method).
1987	SHARP (Japan) merchandises a black and white DSTN-LCD with a phase-difference compensation feature.
1988	SHARP (Japan) develops a 14-inch a-Si TFT-LCD.
1990's	A large display started to be developed through a-Si TFT/STN liquid crystal technology.

2·1·1 Pre-LCD Period

Liquid crystal is derived in 1888, when Reinitzer, an Austrian botanist, who studied a biochemical effect on plants against steroid-compounds, discovered reaction of white cloudiness and vivid blue, which is different from that of crystal solution. He was synthesizing highly pure cholesterol induce to measure a transferring point of the compound.

It was not until the 1920's that Friedel (France) identified the chromatic reaction as not of a crystal phase or of a liquid phase but of an intermediate phase of the two.

In the 1930's, the researchers from Marconi Corporation (England) applied for a patent in order to utilize liquid crystal for industrial use. However, the peripheral technologies were not enough to back up the research, and liquid crystal ended up only to attract many researchers' interest in physics/chemistry fields.

2·1·2 The 1st Stage of LCD Development

The first breakthrough was done by Fergason (WH Corporation, USA) and Williams (RCA Corporation, USA). Fergason invented a thermos-sensor, making use of cholesteric LC's selective reflection effect, and a visible-light modulator for infrared rays, through which he applied for a patent. Williams discovered a electric field effect of nematic LC, through which he applied for a patent in 1962, and the next year released a paper to "Nature". Heilmeier and other researchers (RCA Corporation) to develop the first LCD prototype (digital clock) with use of DSM (Digital Scattering Mode) carried out his research. His releasing a paper to "IEEE" motivated further research for LCD's industrial applications.

The DSM display is brought by the two effects: One is caused by alignment deformation of nematic LC molecular with negative dielectric anisotropy, and the other by light scattering effect which is caused by liquid molecule's hunting movement, born from space electric charge of active ion in the LC. Professor DeGenne's research group (Nobel Prize winner) contributed to this thesis analysis.

Photo 1 The first portable LC calculator EL805.

During the same period of time, CMOS-structured IC with low power consumption was invented in the United States (1963). This invention should be noted since the real development was started after that.

On the other hand, starting with the development and production of the world's first calculator CS10A in 1964, SHARP produced the CS32A Calculator with bipolar IC (1966), followed by the CS16A with MOS-IC (1967). Next was to come a portable calculator with MOS-LSI and low-power display. A portable compact calculator was developed and designed in the late 1971. It came with a lower-power consumption CMOS-LSI and an LCD. It was also capable of AAA-battery operation. A special project S734PT was set up for further advancement. The project S734PT was completed in April, 1973, then the following month the first portable LC calculator EL805 (**Photo 1**) was introduced in newspaper and in June, 1973 it was finally launched in market. This is noted as the first LCD made into practice. The EL805 enjoyed a lot of attention not only because it was a mass-produced LCD-applied product but also because it was the realization of system-on-glass in a way that LSI was accumulated on a glass substrate.

The DMS requires more than 10V driving voltage and a display hood for the light-scattering type of electro-optical reaction. Thus, to make the CMOS drive simple, was needed the transition into low-voltage light-absorbing type of electro-optical reaction.

As for a new electro-optic reaction, a lot of suggestions were reviewed in the related journals from 1968 to 1971 in order to employ light-absorbing methods utilizing deflections. Such methods included; guest-host method, in which liquid crystal molecular move dual-color dye to operate alignment deformation, complex refraction field control method, which implements complex refraction interference, TN (twisted nematic) method, which utilized rotary polarization, and so on.

SHARP encouraged the research for the TN-LCD in the late 1971 while enforcing the research for the DSM to be made into actual use. At that time it was so difficult to obtain liquid crystal material that a special request would often be made to other chemical laboratories outside of the Company for a very small amount of sample LC material.

In October, 1975 the Company's first compact digital clock with the TN-LCD was sold. It was applied with chemically stable azoxy LC material from schiff-base LC material. In 1976, was

Photo 2 A portable calculator with a TN-LCD EL8020.

merchandised a portable calculator EL8020 **(Photo 2)**, which had 0.01W power consumption with the 7mm thin TN-LCD. From this time the biphenyl-base LC material came to be in use for the products. The biphenyl-base LC material, which was composed by Professor Gray (England), proved the LCD technology's advancement in its lifetime and quality. In 1976 a calculator with an LCD came with solar battery driven, in 1977 with 5mm thin card type, and finally in 1770 with 1.6mm thin card type.

2·1·3 The 2nd Stage of LCD Development

As the LSI technology made a progress and the LCD came into use of calculators and clocks to display numbers, the market started to demand an LCD capable of displaying characters and images in the late 1970's. To meet the market needs, the display method for the LCD panel was changed from 8-character segment electrode into XY-matrix electrode. However, the TN-LCD mode had no more than 15 scanning lines (duty ratio), which was capable of displaying only 1 or 2 lines of alphanumeric. The **Photo 3** shows an electronic translator with a 1 line alphanumeric or "katakana" ; the square Japanese syllabary LCD.

Photo 3 An electronic translator with an alphanumeric LCD.

To realize a larger-capacity display, SHARP started R&D on a simple-matrix LCD and an active-matrix LCD in 1976. We succeeded to develop a 5.5-inch B/W LC-TV with a simple-matrix LCD (160 x 120 dots) as the **Photo 4** shows. This was made possible, employing a dual-matrix electrode structure, dual-scanning driver, and dual-LC panel structure, all of which worked together to operate the 120 scanning lines with the 1/15 duty to create a 15-gray scale image.

Photo 4 A 5.5" B/W LC-TV with a XY matrix LCD (160 x 120 dots).

SHARP's LCD research was mainly performed with Te, an element-semiconductor, which has superiority in re-production to a CdSe-TFT, which is a compound-semiconductor particularly focused by WH (USA). With support from JEIDA (Japan Electronic Industry Development Associations) for three years (1979-1982) and also from MITI (Ministry of International Trade and Industry) for two years (1981-1983), SHARP kept on the R&D of a Te-TFT LCD, finally to succeed in the development of a 3.8-inch Te-TFT LCD with 248 x 204-dot character-broadcasting capability **(Photo 5)**.

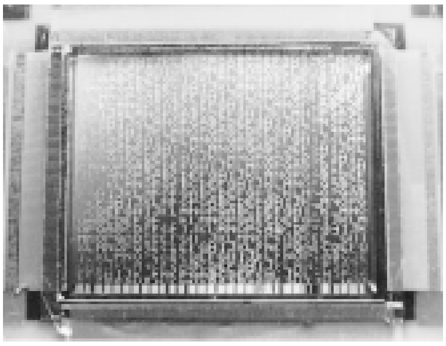

Photo 5 A 3.8" Te-TFT LCD (248 x 204 dots).

2·1·4 The 3rd Stage of LCD Development

Although more and more R&D was carried out on the LCD's larger-capability for both simple-matrix and active-matrix LCDs in the 1980's, it had not led yet to practicalize the LCDs because of the production cost and other challenges. The market scale did not show further progress over approximately 200 billion yen per year, and some would worry that the LCDs would be of no market potential.

With all sluggish situation, some breaking-through suggestions were proposed for both simple-matrix and active-matrix LCDs:
For the former, the LC-layer's twisted angle was widened (i.e. 270 degrees) to bring a striking change in transmittance-voltage characteristics compatible with a high-duty driver. This is the STN (Super Twisted Nematic) technology by Sheffer and et al..
For the latter, Professor Spear and et al. suggested the a-Si TFT technology and Suwa-Seiko Corporation introduced a prototype of a 1.6-inch B/W TV panel with the Si MOS technology and also developed a 2.1-inch color TV panel with the high-temperature poly-silicon technology.

Sheffer and et al. had the STN-LCD implement more than 240 scanning lines, which was extremely a larger number of the conventional LCDs and utilized a intruding reaction by light complex refraction. Thus, in spite of the improved the scanning line number, light intruding reaction made it difficult to see the display because the screen puts on green-yellowish color or blue color. Another problem was that alternative colors were not to be displayed.
To solve these shortcomings, SHARP employed a double-layered STN-LCD **(Photo 6)** to compensate a phase difference, and succeeded in its production in 1987. This made SHARP gain a leading position in the LC industrial field. The method of the phase-difference compensation, which we applied, was backed up with our research on the double-layered LC panel structure of simple-matrix LCD in the late 1970's. This method came to be performed by polymer film compensation, which contributed to reduce size and cost. In addition, the color filter technology allowed for color display. With other new technologies applied, the LCD was improved its balancing quality in display, such as the wave compensation technology (SHARP Addressing Technology and High-Contrast Addressing Technology) and the simultaneous driving method of multiple scanning lines. These have been widely

Photo 6 The first B/W LCD word processor using a doublelayered STN-LCD.

applied to word processors, notebook PCs, and PC monitors.

As to the active-matrix LCD, on the other hand, after Professor Spear and et al. developed the idea of a-Si TFT, a lot of companies competed with one another for the development of the a-Si TFT-LCD. The a-Si TFT's potentialities of large display use and of efficient production, the development of a-Si solar battery, and the improvement in P-CVD device; all these can be said to have accelerated the development of a-Si TFT-LCD. In 1982, Sanyo, Toshiba and Cannon launched a prototype of a-Si TFT-LCD.

SHARP also dedicated itself into the research on a-Si TFT-LCD, parallel with developing the theme "Te-TFT-LCD" supported from MITI, finally to develop a prototype of a 3-inch full-color panel in 1983. After that we put a real emphasis on a project for a-Si-TFT-LCD, setting up a particular production line at our Tenri Factory (Nara, Japan). In 1987 we started to produce and sell 3-inch a-Si TFT-LCDs for LC-TVs applied with a vivid full-color normally-white mode **(Photo 7)**, followed by 14-inch TFT-LCDs **(Photo 8)** in 1988 which rivaled the CRTs. Throughout these developments, SHARP proved that the a-Si TFT-LCD could be a next-generation main FPD technology. Now the s-Si TFT-LCD technology yields a wide variety of LCD applications such as a notebook-type PC, a PC monitor, "ViewCam" and car navigation system.

Photo 7 The first LC-TV product using a-Si TFT-LCD from SHARP.

Photo 8 The first large (14") TFT-LCD.

Details in the recent R&D on LCDs will be reviewed in the following chapter.

2·2 The Recent R&D on the LCD Technology

We have now reviewed that each of the STN and a-Si TFT technologies characterizes the third stage of the LCD development in a simple-matrix LCD and an active-matrix LCD. Today's LCD industries were built up through other technologies for the peripheral materials, optical technology and production technologies for large high-definition panels. The LCD now rivals the CRT in display quality. In this chapter the crucial technologies that brought these technological innovation to the LCD industries.

2·2·1 STN-LCD Technology

The STN-LCD technology is based on a simple-matrix driving method. Its display quality largely relies on elecro-optical reaction, which means that the quality is determined by performance, preciseness and uniformity of the driving circuits including the composing LC material, LC molecular alignment, LC layer thickness, clear electrode, phase-difference compensation film material and driving method itself.

Due to the fact that the STD-LCD is driven by the mean voltage method, the driving voltage ratio (drive margin) of the selective dots and non-selective dots (which perform display contrast) reduces as the number of the scanning lines (driving duty ratio) increases. For instance, even if the dual scanning driving method was implemented (the number of the scanning lines is reduced by half, separating the data line into the upper and below parts), the resulted driving margin shows only 1.0667 (N=240) in a VGA (640 x 480 dots) and 1.0524 (N=384) in an XGA (1024 x 768 dots). Moreover, extremely precise voltage control is required in order to carry out the balanced gray-scale-display free from shadowing and uneven brightness (i.e. less than 0.08%, which is equivalent to 1/64 of the actual driving voltage value.)

The core technologies of the STN-LCD panels are the LC material, LC molecular alignment film and optic phase-difference compensation film, all of which perform optical modulation reaction to voltage value deviance. Other core technologies include the processing technologies to realize the even display on the screen, such as very flat low-resistance substrate clear electrode and highly precise cell thickness controlling structure. Moreover, the high-level even-display control technology and the driving circuit technology are covered so as to compensate the wave distortion caused by electrode resistance and floating capability. The commonly used LC materials for STN-LCDs are compounds of alkyl-base, styrben -base and tran-base, which are specially composed for STN-mode and whose physical specifications are different from those of TFT-application. These materials show an optimal elasticity for stable STN alignment and also rather high value of complex refraction, which allows for an effectively thin cell to improve in response. The spacing technology enables the precise control over every 0.01-micrometer of the LC-layer thickness. The development of panel-glass pasting technology is also contributing to the display quality.

The STN-LCD, however, off-trades contrast for better response by lowered viscosity and narrowed cell thickness (frame response effect). To solve this problem, the frame frequency is increased and the mullet-line simultaneous scanning method is implemented with the direct functional calculation process. SHARP calls each of these new driving technologies the HCSA (High Contrast Sharp Addressing) and the HCA (High-Contrast Addressing). The **Photo 9** shows our recently released 12.1-inch SVGA-HCA panel for notebook PCs, whose contrast ratio is 40:1 and response speed is 150m per second.

Photo 9   A fast response and high contrast HCA-LCD.

Thanks to these remarkable technologies, today's STN-

LCDs is implemented not only in medium-small size portable information devices but also in PC desktop monitors and display panels for notebook PCs. It splits the LC market with the TFT-LCDs and shows a market scale of 2,600 billion yen per year, which is 1/4 of the market share (estimated as of 1997).

2•2•2 TFT-LCD Technology

From the view of the operating principles, the TFT-LCD technology is rather dependent on the TFT-array substrate technology. At the same time, due to the fact that the TFT-LCD optically functions as the STN-LCD does, cannot be ignored the LC material technology as an electro-optical transducer, and nor can the optical material technology such as a phase-difference compensation film, lens and prism.

Originally, the TFT-LCD development was aimed to realize the FDP superior in display quality to the CRT. The researchers all over the world devoted themselves into the TFT-LCD development with this motive for more than 25 years since the suggestion from Lechner and et al. (RCA Corporation, USA) in 1971.

Today the TFT-LCD technology has grown into the industry whose market scale is approx. 7500 billion yen per year (estimated as of 1997). It will soon become a core display technology in the next few years, replacing the CRT, which dominated the market for over 100 years.

The followings show how the TFT-LCD has been developed.

(1) Large-Size & High-Resolution TFT-LCD with a Large Capacity

In the late 1980's when the TFT-LCD started to be developed, the target was a 3-inch (384 x 240 dots) panel for a portable TV. Such application was still in a niche market, which the CRT had not succeeded in. The TFT-LCD, as a new type of display, was expected to break in.

However, the expected trend was changed by a prototype of PC-compatible 14-inch VGA. The TFT-LCD was identified to be suitable as a PC-display device because of its blurless, high-quality image with a high contrast ratio and high resolution.
From this point, the LCD newly entered the PC-display market, which was mainly dominated by the CRT and the mono-color PDP. The displayable picture-element capacity was considerably improved from a PC-standard VGA (640 x 480) to SVGA (800 x 600), XGA (1024 x 768), SXGA (1280 x 1024), and UCGA (1600 x 1280), and what is more, even to the range of 2000 x 2000 picture-elements for a high-definition CAD (see **Figure 1**). In response to these improvements in the high-definition TFT-LCDs, the human visibility according to the resolution was focused for further improvement in a display size. Today a 13-inch display is used for notebook-type PCs, a

20-inch for desktop computer monitors. Further necessity for enlarging the display screen size over 25-inch is assumed to be scarce because of the original purpose for the computer screen use. Thus, the possible screen-size enlargement will be intended for audio visual or public display applications.

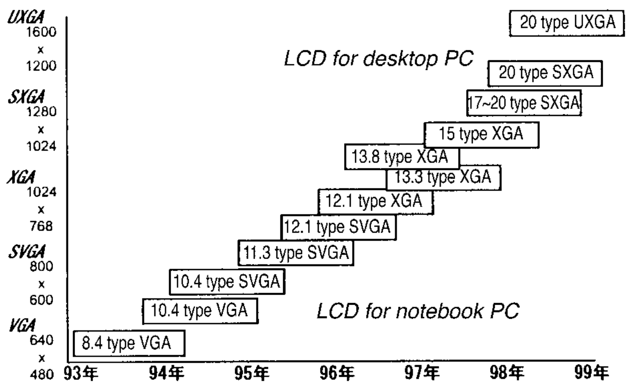

Fig.1 Trends for display contents of the LCDs for PC.

This stream of developments in size and definition was promoted to solve one of the most challenging problems, shading. A low-resistance scanning (gate) bus line made the solution.

A gate bus line used to be composed by materials which had a high-melting point, such as Ta-/Mo-/Cr-basis material. The precedence was taken for the material's heat-/chemical-resistance performance during the process. The reason was because the panels targeted before were used to be small-medium size, which did not require such high definition. However, when it comes to a high-definition large display, high-frequency driving elements need to be increased. That requires a larger gate busline constant, which is more likely to be well affected by the TFT's load capability. A low-resistance busline prevents driving harmonic distortion, which is how a low-resistance busline came into the light. Now such materials are in use: Ta alpha-crystal based on Ta/TaN, and multi-layered materials compounded with Al-basis such as Ta/Al, Mo/Al, Ti/Al, Cr/Al. Al is one of the low-resistance materials, and then Ta alpha-crystal contributes to reduction in resistance. For further process improvement in size, Al and Cu are now being considered as possible materials.

Another challenging problem in putting a large, high-definition panel into use is how dusts and product's uniformity should be managed during the production process. This is rather a time-taking problem to be solved, but crucial from the point of production technology.

(2) Wide-Viewing Angle

As already mentioned in the Chapter 3.1., the TN-matrix LCD has improved in contrast ratio thanks to the TFT active-matrix drive, but its narrow-viewing angle was a problem remained to be solved. It was very crucial because that would allow LCDs to compete against CRTs. Technological discussion was made from a variety of fields of the industry in order to break though the problem **(Table 3)**.

The Super-V is a method suggested by SHARP. It has now been put into practical use, providing two times as wide-viewing angle as the conventional one. The Super-V method is performed by combination of optical phase-difference compensation technology and in-plain switching (IPS)

Table 3 Wide viewing angle technologies of the LCD.

Method	Super-V	IPS	MVA	ASM	4-Domain
Main Technologies	Phase-difference compensation + picture-element segmentation TN	Inner electrode structure	Vertical alignment + picture-element segmentation	High-polymer compounded LC + axis-symmetrical alignment	Picture-element segmentation TN
Viewing angle (RL)	140	140	>140	>140	120
Viewing angle (UD)	110	140	>140	>140	120
Response time (ms)	30	70	30	40	100
Comparative brightness	100	60	70	90	90
Contrast ratio	300	100	300	300	200
Remained problems	Viewing angle for the lower part of the screen	Brightness + productivity	Reliability, production technology	Reliability, production technology	Reliability, response time, production technology

mode technology. The optical phase-difference compensation was performed by the reaction of a special optical film and a dual domain. The IPS method is, however, now proved not to be suitable for portable applications because its optical efficiency is based on the (comb-like) electrode structure. Such structure reduces the optical efficiency in half unlike the conventionally used sandwich-type electrode structure.

(3) Low Power Consumption (Higher Brightness under same power consumption)

Considerable improvement has been achieved in lowering power consumption mainly by advancement of panel aperture ratio, reduction of driving circuitry power consumption, and efficient usage of the backlight.

For better panel aperture ratio, various techniques have been applied, such as employment of low-resistance materials, detailed busline to bring more-precise photolithography, size-reduction of storage capacity with less TFT floating capacity, expansion of picture-element electrode plane with an insulation film structure between layers (SHA: Super High Aperture Ratio Structure), and more precise alignment to the counter electrode. All of these are contributing to the high aperture ratio of 80% in a high-definition 12-inch XGA panel.

As to reduce driving circuitry power consumption, low-voltage LC materials are used because such materials offer a large anisotropy of dielectric constant and little elasticity. A polarity reverse-driving method has also contributed to lower the driving voltage.

For backlight, advancement has been seen in the use of highly effective fluorescent tubes less than 3mm, enhanced light-accumulating and light-inducing boards, and more efficient implementation of polarized light. The yielded result is that 3W (70cd/m^2) in the specifications of a 12-inch XGA panel.

The first-rate low power consumption LCD is a high-reflection color-LCD. Its details are to be reviewed in a different section later.

(4) Super-Large Display

The TFT-LCD size has been improved so far as to the 20-inch for PC applications, which is very close to the ideal size. However, this is not enough for AV applications where realism is required and also for public display applications where a lot of people view the display in a distance. The TFT-LCD size still needs further development.

There are two methods to realize a super-large display: One is to increase a viewing panel size itself and the other is to optically magnify a small-size display and project it.

The first method is processed, using p-Si as semiconductors or using low-resistance metals such as Al and Cu for buslines. It is theoretically possible to design a super-large TFT-LCD more than 40-inch. However, the currently implemented process, materials and production equipment are not sufficient enough to embody a super-large LCD yet.
To break through this problem, employing the element technology from the printing technology has been discussed as a national project GTC, including a highly productive large-substrate compatible patterning technology. Unfortunately, the practical implementation has not been achieved yet.

Taking those facts into consideration, SHARP attempted to use a seamless multi-panel technology. This is a technology, for example, where we carry out optically equal pasting of two TFT panels in center, while keeping a regular space with a picture-element pitch. This method allows two 29-inch panels, which makes the largest glass substrate currently mass-produced (550 x 650cm^2), thus realizing one 40-inch super-large SVGA TFT panel **(Photo 10)**.

There are certain technological challenges remained, such as high production cost when these super-large LCDs are put into general use of visual equipment; for example, home-use TVs and VCTs. One of the possible technologies to solve this problem is the PALC (Plasma Addressed Liquid Crystal) display. The PALC display is an active-matrix LCD that offers high-quality display, and its production technologies are very similar to those of the PDP for super-large screen applications. With a purpose to bring a practical super-large panel to the masses, the PALC display was developed by collaboration of SHARP, Sony and Phillips. A lot of attention was drown to the 42-inch high-brightness, wide viewing-angle ASM-PALC at the 1997 Electronics Show in Chiba, Japan.

Photo 10 A 40" TFT-LCD using a seamless multi-panel technology.

On the other hand, the second method of projection-type display has been making a remarkable progress in the development and practicalization since SHARP launched our first projector into the market. It is now used as a presentation tool for business applications or as an AV display for home or hotel room applications **(Photo 11 and Photo 12)**. In this projector field, poly-silicon TFT technology, instead of the long-standing a-Si TFT technology, has been applied, aiming at the small-sized, high-definition panels. In addition, the display brightness is improving every year with the development of optical technologies such as micro-lens and PS separation/synthesis, and of highly efficient short arc lamp. Nowadays the SVGA projectors with the luminous flux of 1000Lm are on the market.

Photo 11 A LC front projector.

Photo 12 A LC rear projector.

(5) High-Reflection Color-LCD

In order to make a portable electric information device easier-to-use, it is very crucial that displays are thin in size and light in weight and also that the power consumption is kept low. The LCDs consume the least power that any other kind of display does. Especially, the high-reflection LCDs well cope with these issues on size, weight and power consumption, due to the advantageous use of light. That is, the high-reflection LCDs implement external optical source, instead of requiring a backlight. This favors the high-reflection LCDs with a wide variety of applications, ranging from portable calculators and watches, to other electric devices requiring low power consumption.

If meant to be capable of a wide range of color-reproduction, the high-reflection LCDs need a color filter. However, employment of color filter strikingly reduces the light-implementation efficiency rate and moreover, the solution cannot be made simply by replacing a backlight section on a conventional transmissive module into a reflection board.
Thus, it is required that a surrounding light be reflected and gained particularly towards the direction of a display-observer. At the same time, further development needs to be made for a LCD mode that absorbs less light.
A lot of suggestions was proposed from some universities and companies but did not end up with a satisfactory solution yet. Such proposed suggestions were;

i) Implementation of a high-polymer dispersion LC (light-scattering method or a hologram-interference method),
ii) Implementation of a cholesteric LC's selective-reflection reaction,

iii) Implementation of complex refraction in electric field control,
and
iiii) Triple-layered laminating method.

Collaborating with a Uchida Laboratory, Tohoku University, SHARP succeeded to develop a micro reflector structure. This work achieved a real high-reflection 4-color LCD, and its presentation at the SID in 1992 received favorable reactions from the attendants. In 1997, further modification was applied to the high-reflection color-LCDs in order to represent more colors. For instance; an HCR (High-Contrast Reflective) method was developed as a new mode for the LCDs, and with that technique high contrast and multi-colored display performance with high brightness were well-balanced to show more than 260,000 colors. It can be said that SHARP found a way to put a high-reflection color-LCD into actual use in terms of graphics and image. This brand-new type of high-performance LCD is called super-mobile HR (High-Reflection) TFT crystal liquid display. **Photo 13** shows a recently released 6.5-inch HR TFT-LCD with HVGA.

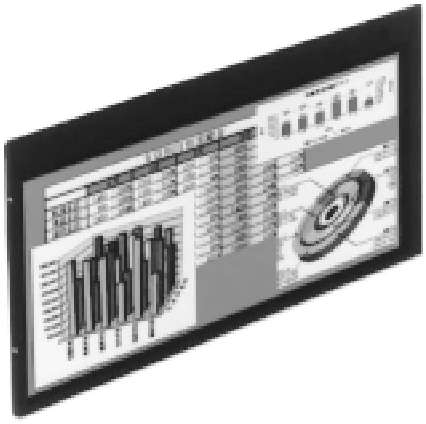

Photo 13 A 6.5" HR-TFT.

Aggressive R&D have been conducted on the element technologies since 1997 as a national project at the ASET. LCD manufacturers including SHARP and related-material manufacturers are on this project with a purpose to realize a high-reflection full-color LCD with excellent brightness, competitive against that of a photogravure. We expect that much will be yielded through the project.

(6) High Functionability (System-on-Panel by Low-Temperature Poly-Silicon TFT Technology)

More functionability needs to be applied to the LCDs in order to add further value to the products. The p-Si TFT is a promising technology that will suit this needs because it monolithically forms a driving circuitry. The TFT-LCD has developed for this purpose. Compared with the s-Si TFT, the p-Si TFT offers an excellent electron/hole mobility in semiconductor layers (hundreds times faster) and larger signal processing capability. Today it can monolithically form not only an LCD drive but also a peripheral electric circuitry function on an LCD panel, which was conventionally done by the Si-LSI. In other words, all this is meant for a concept of 'SOP (System-on-Panel)', where an electric circuitry system is monolithicalized onto a glass substrate of the LCD panel.

With a purpose of practical application, concerned companies have been conducted a wide range of developments for high-performance p-Si TFT as a next-generation element technology. Such developments are made in the device/process technology, production technology, and applied system technology.

2·2·3 Trends of other LC Technologies

(1) Ferrodielectric LCD

The Ferrodielectric LCD (FLCD) is implemented with a liquid phase, called chiral-smectic C phase, which was suggested in 1980. The FLCDs theoretically allow even a simple-matrix display to deal with a large display capacity with a wide-viewing angle and less crosstalk. Such can be done due to the FLCD's advantages: high-speed response of ferrodielectricity, bistability (large memory-capacity) and inner LC molecular alignment. All this has envisioned a possible future technology that will make it possible to produce a high-definition large display, while keeping the production cost low. In 1994 an FLCD with 15-inch SXGA (16 colors) was merchandised for PC monitor applications. This, however, still has some problems to be challenged in terms of the color variations, visibility and operating conditions. A real penetration into the market has not been made yet.

The FLCD is less capable of displaying gray scales because of its original bistablity feature. A gray scale dither drive, which segments space and time, is required in order to compensate for this disadvantage. However, this causes another trade-off for poor performance in appearance, consumption power and shock-proofness. Further advancement in the LC-process mass-production is indispensable, ranging from forming LC-cell thickness over a large plane to controlling 3-dimensional FLCD alignment. Some additional techniques look promising, such as the τ-Vmim driving method and the voltage-withstand device structure.

(2) Anti-Ferrodielectric LCD

Anti-ferrodielectric liquid crystal (AFLC) is discovered by a research group of Tokyo Industrial University, in 1988. The AFLC indicates three phases: no-electric field phase, anti-ferrodielectric phase, and ferrodielectric bistable phase. The latter two are subject to the positive/negative voltage totality. The AFLC's high-speed response and memory capacity are very similar to those of the FLCD, which enables even a simple-matrix to provide a large display capacity. In addition, the AFLC is more tolerable of shock, compared to the FLCD. These advantages are drawing a lot of attentions from the researchers.

Recently a new AFLC material was discovered which does not have its threshold. Implementation of this new material is considered so that an LCD with a TFT active-matrix drive will perform better in high-speed response and wide-viewing angle.

However, the above two techniques require improvement to achieve sufficient display performance. Some obstacles to overcome, for example, are the very limited absolute amount of anti-ferrodielectric compounds, the limited operating temperature range, the insufficient contrast ratio, and the poor response time. It must be said that the actual application of the AFLC depends on the future development of optimal materials.

Other notable LC techniques are a memory display using a cholesteric LC and a bistable nematic LC mode.
The former, cholesteric memory LCD is slow in response. This feature is not applicable to a moving image display. On the other hand, one of its electro-optic characteristics shows valuable hysteresis, and there is a concept emerging to develop an electric paper, enhancing this hysteresis characteristic to provide large display capacity in a simple-matrix structure.
The latter, bistable nematic LC mode, shows similar high-speed response and memory capacity to those of the FLCD and it is still applicable to the existing resource in the conventional nematic LC panels. Thus, the FLCD is also noted as a possible technique for electric paper use.

Conclusion

Today there is over-all prospect to improve the LCD's poor performance in the viewing angle. Four challenges remain to be focused on such as

i) further improvement in productivity to reduce production costs, which will consequently lead the LCDs into a wide range of applications;

ii) the realization of super-low power consumption to forestallment the global warming, as well as the development of the high-reflection full-color LCDs that will offer bright, crisp images equivalent to those of a photogravure;

iii) the development of the system-on-panel LCDs with multiple functions, which will create more added-values via new system devices;

and

iiii) the development of super-high-definition LCDs equivalent to printed/photographed images, which has not achieved yet by the CRT or other conventional displays.

It has been known that a simply prolonged engagement in these challenges will not reach a solution. As for i), for example, almost every company made constant efforts to realize better productivity, and finally those efforts bore fruit. Thus, it is crucial to constantly make efforts to gain a solution in a long-term view.
At the same time, however, it is notable to set aside a time-taking approach. In order to come out of the dilemma, we need a real breakthrough, such as a positive stance of continuous approach to about-face the existing ideas.

SHARP has been successful in going through these technological obstacles, and there is no way for us to stop succeeding in the future as well. There are a variety of technological challenges under way around us. We will come up with a new technology, investigating what is the core of those challenges, compounding them, and converting them. This requires close interaction with people outside of the field, free from the rigid experience in the past.

The LC technology can protect the global environment and promote the cultural development in mankind without any contradiction. We regard it as our pleasure as well as mission to strive and contribute in the LC industry fields.

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