20130218_IEEE_GHN_milestone_Sharp_14in. TFT-LCD 1988

Text: 69 words:

Sharp demonstrated a 14-in. TFT-LCD for TV in 1988 when the display sizes of the mass-produced TFT-LCD and CRT TVs in the largest number were 3-in. and 14-in. respectively.
The breathtakingly high display quality in CRT-size convinced vacillating electronic companies to decide to join the burgeoning TFT-LCD industry, vaulting it to the major league status in emerging full-color portable PCs, and replaced CRTs in TVs about 2 decades later.

The breathtakingly high display quality was technologically that of 3-in. a-Si-TFT-LCD mounted on the 3-in. a-Si-TFT-LCD TV 3C-E1 with its display dot number 384H x 240V put on the market June 1987. Its display dot number was 92,169(240Vx384H), and primary color dots were arranged in a triangle pattern with each primary color dot number 1/3 of 92,169.

One 14-in. TFT-LCD panel was prepared on the mother glass of 300mm x 320mm, the largest mother glass in the world for amorphous-Si(a-Si)-TFT, which was the predecessor of the following a-Si-TFT mother-glass GENERATION competition started around 1990.

□. What is the historical significance of the work (its technological, scientific, or social importance)?

It showed that an ideal display, namely, a flat, low-power, light-weight, CRT-sized full-color video display ,which could be used also in high ambient light, is technically feasible, and that is exactly what had been long waited for to be used in an emerging information age since LCD was press-released in 1968.

Technologically, it showed :

1. a-Si-TFT could be used for CRT size display.

2. Color TFT-LCD could maintain good display quality even in an high ambient light.

3. A large mother glass scheme could work for a-Si-TFT-LCD, which was proved by the high display uniformity across the entire display area. The mother glass 300mm x 320mm was the very forerunner of the mother glass generation competition which started around 1990, 2 years after Sharp 14-in. full color TFT-LCD was demonstrated.

□. What obstacles (technical, political, geographic) needed to be overcome?

Technology wise:

At the time when a mere small 3-in. a-Si-TFT-LCD production was just started with poor yield, unstable and far-from-being-matured production equipment, small output capacity drivers, engineers had to prepare line-defect free TFT-LCD panels with high display quality, meaning large contrast ratio, high color saturation with high uniformity, and they made a precise electrical and physical system analysis and designing and devised redundant pixel and bus line schemes, and employed normally-white LCD operation mode, which was first employed in 3-in. TFT-LCD panel, and developed the TFT-LCD panel and its driving scheme to achieve higher contrast ratio, better gray scale and full-color rendition, wider tolerance in temperature and cell-gap variations, leading higher display uniformity across the entire large display area, than normally-black mode could achieve.

Organization management wise,

Sharp's first application of TFT-LCD was television which is supposed to be exposed to "critical" consumers 3-5 hours everyday for more than 10 years.

So, from the very begging of development project, TV business group, who understand the market, located in Yaita-shi, Tochigi-ken, and TFT-LCD research group located in Tenri-shi, Nara-ken, worked closely; even though, two places are about 600km apart.

TV group, headed by Magohiro ARAMOTO, joined by Shuhji KOHZAI later on, showed the clear target specifications and evaluation methods to TFT-LCD research group; TFT-LCD research group, headed by Masataka MATUURA, achieved and acquired them.

In the production project, LCD business group, headed by Mitsuo ISHII, located in Yamato-Kohriyama-shi, Nara-ken, joined the project, bringing in panel production technology including large mother glass handing know-hows and the world-first TFT-LCD factory was build in the precinct of Research and Development group, near the TFT-LCD research group.

The 14-in. TFT-LCD panels were prepared by using the production line.

There were lot of fierce arguments and misunderstandings among three groups, but those were suppressed and solved by tightly sharing the common mission among the groups: Make TV displays for our TVs !

□. What features set this work apart from similar achievements?

At the very beginning of a-Si-TFT-LCD business startup, this work clearly showed a-Si-TFT-LCD have the potential to replace monster CRT in the coming information age by its superior characteristics: flatness, light-weight, small power consumption, high saturation full-color rendition, high readability in high ambient light, realized on the 14-in. display size, the most dominant size in the contemporary market by using the technology which was developed to mass-produce twenty 3-in. TFT-LCD TV panels laid out on the mother glass of 300mm x 320mm dimensions.

The high display quality was brought about by the fierce battle and cooperation between TFT-LCD research group and TV business group.

TV business group knew the market and joined the development project from the very beginning and gave a clear display quality target to TFT-LCD research group to achieve and make the TFT-LCD a viable display technology against CRT dominance.

TFT-LCD research group accepted the challenge and made it.

* *

General Description:

The display quality of the 14-in. TFT-LCD was that of 3-in. TFT-LCD mounted on 3-in. LC-TV 3C-E1 put on the market June 1987, one year before the 14-in. demonstration.

3-in. TFT-LCD panels were mass-produced in the TFT-LCD production line which adopted the largest TFT-LCD mother glass in the world, and twenty 3-in. panels were laid out on the 320mm x 300mm mother glass; one 14-in. TFT-panel on the mother glass.

In July 1987, the state of the art of thin-film-transistor liquid-crystal displays(TFT-LCDs) was the size of three inch diagonal. The small LCDs were used as displays of wrist watches and pocket calculators, using simple-matrix LCDs.

Simple-matrix LCDs were also used in small TVs and portable PCs with poor display qualities: large response times, low contrast ratio, large cross talks. Improvement needs were larger for full-color displays where displayed image must be BEAUTIFULL with larger contrast ratio, higher color saturation, shorter response times and delicate gray scale rendition.

Dominant displays used in TV and PC were CRT in those days, and alternative technologies were eagerly searched for: amongst candidate technologies were EL, Plasma, and TFT-LCD.

All candidates were flat panel displays to handle larger display contents with big portability to meet the needs of rapidly evolving information age.

Sharp gave the first priority to TFT-LCD with EL and simple-matrix LCD studied with less emphasis, and did not do any work on Plasma display because Plasma display was after all a kind of vacuum tube based on discharge, and thought to have limited application products in the information age when portability, low power consumption and large information contents, including full color rendition, were key words.

To make the most of limited research resources, EL was later eliminated from the TV candidate list because it need higher operating voltages and poor full-color possibility even though Sharp pioneered and lead thin-film EL display research and mass-production:

Sharp 6-in. 320H x 240V dot thin-film EL went to the moon in a Space Shuttle Discovery mission in 1985 mounted on GRiD Compass 1101

Sharp started research on TFT-LCD in 1975, just 2 years after it mass-produced LCD for the world-first "C-Moss calculator with LCD" in 1973, to extrinsically increase multiplex number, or scanning line number, and hence pixel number to realize large information content display with small thickness, small power consumption and small weight.

Sharp made a decision to mass-produce a-Si-TFT-LCD for Sharp's first color LC-TV in A190 project team(A190PT) which started May 1984, and ended October 1985.

A190PT was comprised of TV business group in Yaita-shi, Tochigi-ken, and TFT-LCD research group in Tenri-shi, Nara-ken, and its target was to decide the driving technology to be used for the Sharp's first color LC-TV.

The technology candidates were a simple 120-multiplex driving and a-Si-TFT driving. A thorough study was done by preparing the prototype panels for each technology with the same specifications of 3.2-in. diagonal size and 240V x 255H display dots.

TV business group insisted display quality come first; production cost second.
a-Si-TFT-LCD won the race by larger contrast ratio, smaller response times and larger viewing angle; even though, its production cost estimated to be far larger than that of . a simple 120-multiplex driving.

The next project team A208PT was consecutively setup which started November 1985, and ended March 1987. Its target was to build a-Si-TFT-LCD factory and to start Color LC-TV business.

A large mother glass should be adopted to reduce the TFT-LCD panel production cost.

The mother glass size was decided, by Sharp LCD research
group headed by Masataka MATUURA and Fumiaki FUNADA to accommodate twenty 3-in. and twelve 4-in. TV panels with 3-to-4 display aspect ratio, in cooperation with

Sharp LCD business group, located in Yamato-Kohriyama, which had been using 300mm x 324mm mother glass from 1982 to produce STN-LCD panels for Nintendo game&watches first, and for word processors, note PCs later on aiming at A4, 210mm x 297mm, diagonally 14.3-in. size display.

The main production processes to produce TFT-LCD panel are thin-film deposition process and photolithography process to fabricate TFTs and LCD process.

Thin-film solar cell provided equipment large enough to deposition process to accept the 300mm x 320mm mother glass; the STN-LCD production process already used, in 1985, 370mm x 480mm mother glass, larger than the 300mm x 324mm mother glass, and two process did not have serious issues to be cleared.

The biggest issue to be cleared before deciding to adopt 300mm x 324mm mother glass was the development of the an exposure system of photolithography to prepare TFTs on the largest-ever mother glass, because even the largest exposure system used in semiconductor LSI process was for a mere 6-in. disk wafer.

Sharp approached Nikon and asked to develop an exposure system for a 300mm x 320mm rectangular mother glass with firing eagerness, and Sharp's eagerness resonated with that of Nikon, and the both agreed to work together to start developing the exposure system using "stepper" scheme.

TV business group in A208PT continuously insisted and demanded display quality improvements, in particular, in black level, gray scaling and faithful color reproduction in the darker region where naked eyes are sensitive.

LCD operation mode adopted in TFT-LCD panel in those days was Twisted Nematic(TN) mode, and it has two operation mode: one is normally-black mode: display appears black when no operating voltage is applied; another
normally-white mode: display appears white when no voltage is applied.

Many research institutions had been working in fierce competition to develop TCT-LCDs, and adopted normally black mode because it required a smaller applied voltage than normally white mode, and was thought to be better than normally white mode in terms of power consumption, and ,more importantly, life time of TFTs which was very unstable: on and off currents changed and threshold voltage shifted, in particular, in high temperature operation. Sharp also adopted normally-black mode at first.

TV business group was not satisfied at all with the display quality level normally-black mode provided, even though the display quality was far better than that of a simple multiplex driving provided as of established in A190PT, because TV business group compared TFT-LCD display quality with that of CRTs; not with .that of a simple multiplex driving.

LCD research group tried to improve black level, gray scaling and faithful color reproduction in the darker region by developing new LC materials, LC molecule orientation means.

One day, Naofumi KIMURA, in LC research group made a demonstration, under the leadership of Yutaka ISHII, using a wedge-like cell-gap test device trying to clearly show the coloring effect of the operation region around the black-to-gray region where naked eye are more sensitive than brighter region and more critical in TV display: the result was obvious and normally-white mode showed far less coloring than normally-black mode under the applied voltage region meaning normally-white mode had smaller optical dispersion than normally-black, and would give more beautiful colors than normally-black mode.

Then, display quality comes first, and driving scheme was changed to give inverted-polarity voltage to the counter electrode of the TFT-LCD panel and hence larger video signals to the LCD, about 1.5 times larger than that of normally-black mode, and TFT process parameters were also reexamined to get more stable TFT characteristics under larger TFT operation voltage.

Sharp's first color LC-TV, 3-in. a-Si-TFT-LCD TV 3C-E1 with its display dot number 384H x 240V, was mass-produced and put on the market Jun 1987, half a year later than the originally scheduled Christmas season of 1986.

A-Si-TFT-LCD TV 3C-E1 was another first: first TV which was mounted with the display made by Sharp in house, not outsourced.

Competition was fierce and the process was not profitable.

As a next step, engineers had proposed going up to 4-in. for TV, portable video-players and PDAs , then 5.7-in. for TV and car-navigation displays for mass-production.

Isamu Washizuka, Division General Manager of Liquid Crystal Division, accepted those proposals, and at the same time, gave a mission to look into the future, and to search for TFT-LCD technology capability for TV, and instigated young engineers to study and propose larger display prototype fabrication plans without giving clear target size numbers.

Around middle of 1987, a voluntary project team was set up, headed by Mitsuo ISHII, whose leading members were Toshio AKAI for product planning role, Kohzo YANO for process engineering role and Hiroshi TAKE for electronics engineering role.

Numbers of panels, with the aspect ratio of 4:3 for TV, prepared on a rectangular mother glass substrate change stepwise.

The study showed the mother glass could accommodate four 6.6-in. panels, two 8.9-in. panels, one 14-in. panel.

The project team almost reached a consensus to adopt 8.9-in. size for a challenging target: 6.6-in. seemed to give only a small impact; 14-in. seemed to be too risky to get good panels, meaning with high display uniformity across the entire display area, no-line defects and acceptable dot defects by infant technology and equipment.

TAKE made a phone call to Magohiro ARAMOTO, general manager of TV Division located in Yaita-shi, Tochigi-ken, who was the head of a project team, comprised of TV group and LCD group which had made a decision Sharp should adopt TFT-LCD for color TV, and had always set a clear and severe target of display quality TFT-LCD group had to clear, saying this target must be cleared for TFT-LCD to be viable in TV consumer market. TAKE asked ARAMOTO on the phone what would be the minimum size of TFT-LCD to be widely used by people.

ARAMOTO's right-away answer was 14-in. as 14-in. CRT TV was mass-produced in the largest number in the Japanese consumer market in those days.

TAKE, evaluation and characterization research engineer by background, knew the difficulty to prepare 14-in. panel using the same process and equipment used to mass-produce 3-in. panels with poor yield, but decided to accept ARAMOTO's number 14-in., saying to himself the possible largest size on the mother glass would show up, more clearly than smaller sizes , problems and issues TFT-LCD had to solve and tackle with to be a viable technology in TV and other markets dominated by CRTs.

The panel should be compatible with NTSC/M TV system, and display dot number was decided to be 642Hx480V with available analog driver-LSI output numbers taken into consideration. The trios of red, green and blue primary color dots were arranged in a triangle pattern to maximize the resolution with the limited display dot number.

The target TFT-LCD panel specifications was accepted in the project team after YANO made a thorough review of the TFT-LCD process and equipment in the 3-in.-mass-producing factory to make sure 14-in. was NOT impossible , and authorized by WASHIZUKA.

WASHIZUKA, then, had AKAI sent directly to Haruo TSUJI, president of Sharp corporation, to get a fund for 14-in. TFT-LCD as LCD Division did not have any extra budget to support 14-in. project, because he knew TSUJI was the very person who most eagerly wanted to produce TV displays IN HOUSE, and was weak to a proposal from the bottom, in particular, from a young guy.

AKAI went to TSUJI alone, and made a presentation and described 14-in. TFT-LCD project, and requesting to support the project by supplying the fund.

Understanding the meaning of the size 14-in., the dominant size of color CRT TV, TUSJI accepted the request and instructed the department concerned on the spot to prepare the fund for the project.

One of the team members recalls the events that happened after that. Washizuka insisted on using only existing manufacturing equipment. This meant they now had to use the stepper that had been used for the 3-in panels for the exposure of a 14-in panel. They subdivided the panels into nine areas and used the stepper nine times. The major problem was the length of the conduction lines. They knew the statistical value for line breaks from their experiences in manufacturing the 3-in panels. By extending the statistical values, they predicted that the 14-in panel was not going to make it, if existing design rules were used. They brainstormed and came up with the idea of subdividing a dot into four identical subdots. The subdots were driven by two source lines having identical signals and with two gate lines also having identical signals. The source lines were driven from the two ends of the panel; so were the gate lines. With this four-fold redundancy and two-end supply scheme, even if there was a break in one line, the signal could be propagated without interruption. By using four identical subdots, a defect in one subdot was not noticeable when a moving picture was displayed. Three dots were arranged in a triangular shape to maximize display resolution with limited dot numbers—each having a red, green, and blue filter, thus, forming one pixel. The pixel had 12 subdots and the panel was made of 1284 960 subdots. Except for the conduction line, they did not expect too much of a problem. The production facility, however, was in almost full use for manufacturing the 3-in panels. Yano quietly pushed a panel through the manufacturing line whenever he found a short period of time when the line was not being used for production. The experiment was a so called "Friday afternoon" experiment. Having been started in August 1987, the process of pushing the panel through the production line was finally finished in February 1988. To the surprise of all the people involved, the first 14-in panels looked okay when examined by the naked eye. They secured four good panels. The next task was to operate the panel with appropriate peripheral circuits. Take recalls that a module group had prepared an application-specific integrated-circuit controller. As for the drivers, they did not have time and money to design a new one, so they used the drivers for the 4-in display. Even the source and gate lines were driven from both ends, he had to operate the driver at three times its specification. The 4-in source driver was designed to operate at approximately 6.5

MHz. Instead, it was operated at 13 MHz. The driver overheated and required a fan cooler. In April 1988, they tested the panel. The first trial exhibited only a black picture. Examining the problems and fixing them, they could demonstrate a still picture, but the size in the horizontal direction was one-half the full panel size, which meant that the source driver clock was operating at only half the required frequency. By brute force, they gradually increased the voltage of the logic circuit. Suddenly, a full-size moving picture appeared, but the picture showed a long tail when tracing a fast moving object.

Engineers needed another day to fine-tune driving circuit parameters to make the most of 14-in. TFT-LCD panel characteristics, and finally succeeded in demonstrating the 14-in full-color full-motion display with sharp and vivid color: high contrast ratio, high color saturation, quick response times, in particular, the size of 14-in. of that display quality was formidable even to the 6-engineers' eyes which had got accustomed to a small 3-in. TFT-LCD whose properties in room ambient brightness, had appeared to be better than those of CRTs, which had not been recognized clearly before.

The size of 14-in. disclosed the 2 intrinsic properties of a color-TFT-LCD which brought about a different level of display quality, in particular in room ambient brightness, than that of CRTs and surprised 6 engineers who surrounded the 14-in. TFT-LCD displaying laser-disk test movies.

The first intrinsic property is "low reflection" caused by micro-primary-color filters provided to every display dot; the second "sharp contrast-resolution MTF(Modulation Transfer Function) curve shoulder" by sharp display dot edge which is independent of display brightness.

Sharp 14-in. TFT-LCD demonstration clearly showing the possibility of CRT replacement in 1988, at least display qualitywise , was a product of more than 4-year close cooperation of Sharp TV people located in Yaita-shi, Tochigi-ken, and TFT-LCD people in Tenri-shi, Nara-ken.

The 2 properties are independent of display sizes: 3-in. had been simply too small for the properties recognized by naked eyes.

Subsequently, the panel was shown to the president. The panel was too good to be true. His first reaction was that Washizuka was fooling him with a phony set up; it was only sometime later that he realized to his surprise it was the real thing.

On June 24, 1988, Sharp announced the 14-in TFT color LCD unit [113] , followed by the technical presentation of [114]. The display was 27-mm thick, including a back light, approximately 1/13 of a conventional CRT display, and its weight was 1.8 kg, approximately 1/4 of a CRT display. Most importantly, the display size of 14 in was the minimum required for a television receiver serving ordinary households and the display could be mounted on a wall.

The announcement sent a message to engineers and managers that TFT-LCDs, which had been serving the niche market for portable 3-in. TVs, and PDAs, now could serve the market for home appliances such as television receivers. and emerging portable PCs, in particular, color note-PCs for business use.

portable PCs

The world first laptop PC , TOSHIBA T-1100, was put on the market in 1985 with 640Hx200V dot black/white simple-matrix LCD.

The first 640Hx480V(VGA) dot black/white simple-matrix LCD was mounted to Compaq Portable SLT/285 in 1988.

Portable PCs with black/white LCDs had always a video terminal supposed to be hooked to color CRTs.

Electronics giants such as Toshiba, IBM, and NEC, which had been performing only research into TFT-LCDs, but were not involved in the business of manufacturing them, now joined the burgeoning TFT liquid-crystal industry too to meet the emerging color portable PC demand.

The 14-in display development vaulted the TFT-LCD industry to major-league status. The door to TFT-LCD industry was open!

The world first wall-hanging 8.6-in. color TFT-LCD TV was put on the market in 1990 by Sharp; the world first note PC with color TFT-LCD in 1991 by NEC.

In 2001, Sharp launched AQUOS Big-Bang operation, and put 3 TVs: 13-in., 15-in. and 20-in. at a time to the market to replace CRT TV in the Japanese Sharp market by the end of 2005, and this operation lead to the avalanche of CRT to LCD shift in TV in the world market.

When he invented the Dynamic Scattering Mode LCD in 1964, George Heilmeier of RCA Laboratories thought a wall-sized flat-panel color TV was just around the corner [9]; as a matter of fact, it was far short for a television display. Finally in 1988, his dream of the wall-hanging television became a reality after a quarter of a century. In The Wall Street Journal [17], Heilmeier remarked: "I think you need to give the credit to the people who persevered and worked on LCDs for 25 years. I don't spend too much time wringing my hands about it, but I have a lot of satisfaction knowing we had the same vision in the 1960s."

The Active-Matrix TFT display developed in 1988 and its descendants are now used in almost any electronic equipment. The LCD industry took over CRT industry in 2001 (Table 1), and in the-number-of-unit wise in 2005 [1]

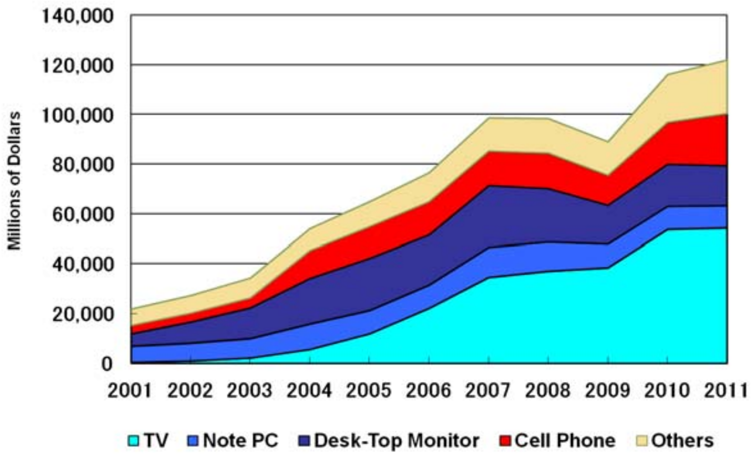
Among various technologies, LCD now dominates the electronic display market (Table 1).

	2,000	2,002	2,004	2,006	2,008	2,010
AM LCD	16,797	18,201	58,872	71,184	95,249	109,445
PM	5,570	5,137	6,893	5,108	3,184	

LCD						
all LCD	22,367	23,338	65,765	76,292	98,433	109,445
CRT	23,400	20,086	18,907	16,435	4,518	1,870
PDP		2,203	5,490	7,688	6,793	7,800
OLED		92	410	550	610	1,467
Others		1,306	1,402	1,457	1,441	1,460

Table 1. Electronics Displays. in unit of Million dollars, all sizes, AM and PM (IHS iSuppli)

The use of Active-Matrix LCDs started from Note PC and Desk Top Monitor in 1990s, and then moved to TV in late 2000s (Fig. 17).



HS iSuppli)

Today, the number of LCDs in consumer's and businessman's use is considered to be over 9.4 Billion units world-wide (accumulating the shipments of TFT-AM LCDs for phones, monitors, PCs, and TVs from 2009 to 2011; IHS iSuppli). The number is greater than the world population of 7 Billion. The invention of LCD is not only one of the greatest technical achievements in the 20th century; it has greatly enriched our life and enhanced business activities.

TAKE now recalls an episode in SID '84 held in San Francisco: he was on the panel, chaired by Dr.Lalatos from Xerox, Rochester, discussing future TV displays.

a- Si TFT-LCD, p-Si TFT-LCD, and CRT were taken up. TAKE represented a-Si TFT-LCD technology.

Toward the end of the panel discussion session, a question from the audience was made to him, saying "Do you think it is possible to make 14-in. display with a-Si TFT technology?"

His answer was:

I have a faith in a-Si TFT technology, and it's quite possible a-Si-TFT could be used for 14 display.

But, I have to quickly add a dictionary says "Faith means to believe without clear evidence".

The audience went into a big laughter.

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