Prospect of LCD Technologies

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Abstract

Active-matrix LCD became the winner for notebook and PC monitors. In the digital society, PDP and TFT-LCD TVs are currently competing for high definition display. The success of TFT-LCD HDTV may rely on the cost-down of its process and materials down to that of PDP because the performances of the competing two displays are not so different. The low-temperature poly-Si technology is used for mobile displays, aiming the system integration including microprocessor. The commercialization of flexible TFT-LCD will take time, but will be dominant mobile displays in 10 years together with flexible AMOLED.

Introduction

Thin-film transistor (TFT) liquid-crystal display (LCD) is widely used for PC monitor, TV and mobile appliances [1]. The mother glass size is increasing continuously to have a higher throughput to reduce the production cost. With the increase of mother glass size the large TFT-LCDs were developed up to 82". Therefore, the next target is to realize low-cost, large area LCD TV for high vision TV.

Low temperature poly-Si (LTPS) has been studied intensively to realize the system on glass (SOG)[2]. Small displays for DSC, PDA, and mobile phone are currently popular with LTPS TFT-LCD. The disadvantage of LTPS technology is the higher production cost compared to a-Si:H TFT. To realize the large area display for PC monitor and TV, LTPS manufacturing cost should be comparable to a-Si:H TFT. Therefore, the nonlaser crystallization techniques are intensively studied.

In order to achieve a low-cost AMLCD, organic TFT (OTFT) can be a switching device because the performance of OTFT is similar to a-Si:H TFT. The printable TFT by using an inkjet can be a low-cost device. The inkjet can be also used to make color filter, spacer, and alignment layer [3].

However, in order to apply OTFT to AMLCD, the TFT should endure during the LCD process, which is around 150^{o}C on plastic. The water vapor and oxygen exposures to the OTFT in ambient air can degrades its performance. Note that organic semiconductor can be damaged by vapor and oxygen adsorptions. Therefore, suitable passivation layers are necessary.

AMLCD on plastic substrate is actively studied for light-weight, mobile applications. To realize the low temperature TFT and LCD process, the improvement in the materials of plastic substrate and for LCD cell, color filters are to be developed.

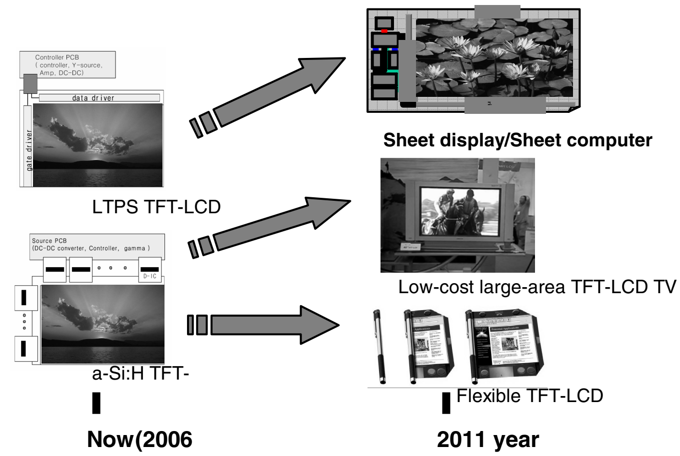

Figure 1. Forecast for the development of TFT-LCDs: Large-area low-cost AMLCD; sheet computer/sheet display (SOG); AMLCD on plastic..

Low-cost large-area AMLCD

Hydrogenated amorphous silicon (a-Si:H) thin-film transistor was developed by LeComber [4] and its application to liquid-crystal display was also proposed by his group [5]. This is used to make most of TFT-LCD currently used for notebook, PC monitors and TV.

Samsung Electronics and LGPhilip-LCD (LPL) are competing to develop large area TFT-LCD. LPL will develop 100" LCD soon. Samsung and LPL use a PVA (patterned vertical alignment) and IPS-liquid-crystal modes, respectively for large area displays such as TV and big monitor. The recent development of 82" TFT-LCD and commercialization of 65" LCDs open up a new competition between TFT-LCD and PDP in HDTV display [6]. This is due to the remarkable improvements in LCD performances such as viewing angle, response speed and color garmut. The disadvantages of the PDP as compared with LCD were resolution, power consumption, depth, weight and contrast under bright condition. However, these were improved remarkably recently, so that ordinary people think the difference in display quality is not big. Therefore, the most important issue is the cost down.

The RC delay in TFT-LCD becomes more serious issue as the panel size increases. The metals such as Cu, Ag and Al have low resistance, but they have manufacturing issues such as adhesion to the substrate (Cu and Ag), electro-migration (Ag), hill-rock (Al) and diffusion to the Si (Cu, Al). Note that Cu was implemented in the manufacturing of LCD by LPL.

The a-Si:H TFT adopting Cu and silver gates have been developed with Cu (Mg) and Ag-Pd-Cu (Ag-0.8 Pd-1.0 Cu wt. %) [7]. A high-resolution (17") TFT-LCD has been developed by using copper source, drain and gate electrodes by LPL [8]. Table 1 summarizes the physical properties of the metal bus lines for large-area AMLCD.

Table 2 shows the advantages of the Cu bus lines [8]. The aperture ratio can be significantly increased by using Cu lines.

Table 1. Properties of Metals used for AMLCD.

Metal	Resistivity (u-ohm)	Melting Temp.	ITO contact	Issuses
Cr	25.2	1030	O	
AlNd	5.1		X	
Al	3.3	660	X	Process
Cu	2.1	1083	O	Adhesion Diffusion
AuPdCu	2.3~4.9		O	Adhesion
Ag	1.91		O	Process

Table 2. Comparison of conventional metal line with Cu-bus line (15.0" UXGA).[8]

Specification			15.0" UXGA(Al)	15.1" UXGA(Cu)	Comment
TFT Array	Gate width		30 μm(AlNd)	19 μm(Cu)	
	S/D width		9 μm(Mo)	5 μm(Cu)	
	Aperture ratio		38%	51.40%	35.2%↑
Panel	Luminance		150cd/m2	199cd/m2	32.0%↑
	Conductivity extra	Flicker	-23.4dB	-27.1dB	
		Line Load (RC) (Gate/Data)	2.6 μs/2.76 μs	1.84 μs/0.41 μs	-Gate:30%↓ -Data:85%↑

For TV applications fast response time and high color gamut are required. In the IPS mode, reducing both cell gap and rotational viscosity (□) of LC are required to obtain fast response time. However, reducing a cell gap leads to increase the dielectric anisotropy (□□) of LC to lower driving voltage. In addition, the mode requires relatively lower birefringence (□n) than that of TN mode to maximize light efficiency. Therefore, in the IPS mode, the LCs with high □□, low □ and low □n are under developing and some LCs are achieved using the –CN LCs.

In VA mode, owing to bend deformation of the LCs from vertical alignment, response time of < 4 ms is already achieved. At present, the LC with low □ is under developing to decrease the gray scale response time. Furthermore, the driving voltage is relatively high in the VA mode, so the LCs with high □□ and low □ are under developing.

Process simplification for TFT-LCD is the most important issue for its cost-down. Double slits in the mask inducing the difference in the PR thickness can give the solution for 4 mask process [9]. Three mask processes were developed last year by LPL using a lift-off process for ITO. The number of masks for TFT array required to make TFT array are decreasing and eventually no mask process can be developed by using printable data line, TFT, alignment layer, spacer and color filter.

The OTFT is extensively studied for the application to the displays because of the possibility of low-cost process. OTFTs can be used in active-matrix backplanes for low-cost AMLCD.

There are two methods for forming OTFT; thermal evaporation and printing. The performance of OTFT by evaporation is better than inkjet printed TFT, but the cost of printing can be much lower. The ink-jet printing for OTFT materials of polymer semiconductor, gate insulator, and organic electrodes are probing technologies for low-cost process on flexible substrates. Ink-jet printing seems to be one of the most promising techniques for low-cost AM with polymer semiconductors. The on/off current ratio of ~ 10^7 and a field effect mobility of >0.03 cm^2/Vs for the polymer TFT have been realized with this method by our roup [10].

Ross Young[11)] reported the cost competition of TFT-LCDs between Japan, Korea and Taiwan. Korean manufacturers, Samsung and LPL, made vertical integrations for materials and component, which is a big advantage to reduce the material cost. Table 3 depicts the cost per panel.

Table 4 indicates that the manufacturing cost of TFT-LCD in Korea is less than that of Taiwan or Japan. This trend will continue for the time being even though Chinese companies increase the volume of TFT-LCD[11].

Table 3. 15" Costs for 1100 × 1250mm lines by countries in 2003.[11]

Yielded Costs	Japan	Korea	Taiwan
Components Cost	$105	$95	$102
Personnel Cost	$16	$8	$9
Depreciation	$20	$20	$20
Indirect Expense	$16	$13	$14
R&D/Royalties	$4	$3	$5
Overhead, Sales Expense	$14	$12	$8
Sales Total Cost	$175	$151	$158

Table 4. 17" Costs/Price by Fab.[11]

Year	2002	2003	2004	2005	2006
730 ´ 920 Japan	**299**	**251**	**226**	**209**	**178**
730 ´ 920 Korea	**253**	**214**	**191**	**162**	**136**
730 ´ 920 Taiwan	**267**	**224**	**202**	**188**	**175**
1100 ´ 1250 Japan	**302**	**239**	**207**	**188**	**173**
1100 ´ 1250 Korea	**262**	**206**	**181**	**165**	**152**
1100 ´1250 Taiwan	**269**	**213**	**185**	**169**	**155**
17" Price	**328**	**244**	**202**	**194**	**191**

System on Glass (SOG)

Several techniques could potentially be employed to yield high-quality poly-Si with large-grain, low grain boundary defects, and high carrier mobility. These can be advanced laser crystallization and advanced metal-induced crystallization (MIC) of amorphous silicon (a-Si). Table 3 illustrates the technology roadmap of LTPS.

Table 5. Technology Roadmap of LTPS.

Year	2003	2006	2010
TFT (Channel)	**Poly-Si 5μm**	**ELA, CGS, 5 ~ 3μm**	**Single-grain TFT, ~1.0μm**
Mobility (cm2/Vs)	**<100**	**<200**	**400**
Clock Frequency (MHz)	**5 ~ 20**	**30**	**100**
Circuits	**Drivers Shift register**	**Graphic Interface DAC**	**16MB Memory 32bit Microprocessor**
System	**Driver Integration**	**Early stage of SOG**	**Sheet display Sheet Computer**
Core Technologies	**Low cost poly-Si Low T SiO2**	**CMOS process Wiring, TFT, Cost**	**Single grain TFT LT oxidation Bus lines**

The laser crystallization has been widely accepted as the most promising method for high-performance, low-temperature poly-Si. This technique has been adopted in the LTPS mass-production. However, the cost-down and the realization of system on glass with a LPTS have been the important issues. A big advantage of ELA is the use of the glass substrate even though the Si is molten during a short pulse irradiation. It has been the main issues to enlarge grain size, to reduce grain boundary defects, and to reduce the ingrain defect in LTPS. Especially, sequential lateral solidification (SLS) [12], phase-mask modulated ELA (PMELA) [13] and sequential lateral crystallization with CW laser [14] were introduced to enlarge the grain size by means of spatial heat flow modulation. Temperature gradient is artificially controlled in a-Si layer upon laser irradiation. The material property of the poly-Si by these advanced techniques is comparable to that of SOI [15].

The drawback of the ELA poly-Si is the high manufacturing cost compared to the a-Si:H because of higher process cost due to the use of laser and a rather complicated AM structure for displays.

The TFTs with CW laser annealed poly-Si exhibited the field-effect mobility of 566 cm^2/Vs and 200cm^2/Vs for n-channel and p-channel, respectively [14]. Note that solid-state laser power is more stable than excimer laser.

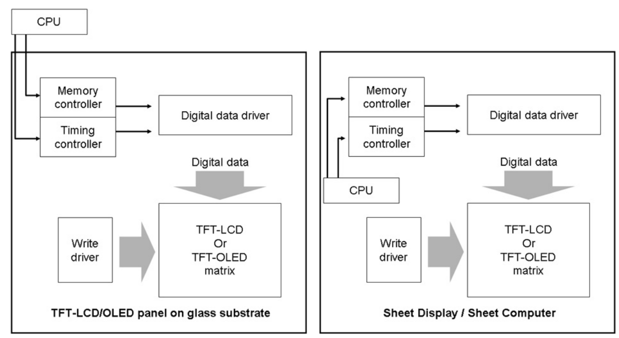

Figure 2. The road map of SOG with LTPS.

Metal-induced crystallization (MIC) of a-Si is a solid phase crystallization with accelerated crystallization speed without an incubation time for nucleation, so that the crystallization temperature can be as low as ~500^{o}C. To improve the material property of MILC poly-Si a CGS (Continuous Grain Silicon) was introduced[16]. The ingrain defects can be removed by ELA or by high temperature annealing at >900^{o}C.

We developed a giant-grain poly-Si by a MIC through a cap layer.[17,18] The grain size can be as large as 100 □m and the field-effect mobility of the p-channel GGS TFT can be as high as 120 cm^2/Vs.

Flexible AMLCD

All organic displays, composed of organic materials for TFT and display, can be an ideal device on plastic substrate. However, inorganic TFTs with a-Si:H and poly-Si, can be an immediate solution for the AM on plastic. The plastic for the TFT should be optically transparent and have no optical anisotropy.

Because of the thermal stress due to the difference of CTE (Coefficient of Thermal Expansion) between plastic and inorganic layers (a-Si:H, SiN_x), the substrate is bent considerably or the inorganic film deposited on plastic can be peeled off from the substrate. Therefore, the substrate temperature should be as low as possible. However, the TFT performance degrades as the temperature is lowered. Therefore, He and/or H_2 dilution in the silane plasma are used to improve the material properties of the films deposited at low temperatures (<150 ^{o}C) [19]. The field-effect mobility of ~0.4 cm^2/Vs and on/off current ratio of $>10^7$

have been obtained on the plastic substrate at the substrate temperature of 150^{o}C [20]. Figure 3 shows a 7” TFT-LCD on PES developed recently by Samsung in 2005 and Table 6 shows the specification of the display.

Poly-Si TFT on plastic has been studied for driver IC and display on plastic. The ELA on the a-Si on plastic can give a solution for the poly-Si TFTs on plastic but the processes for the poly-Si and SiO_2 and activation of the n^+ layers are quite complicated even though a TFT on plastic with a field-effect mobility of high than 200 cm^2/Vs was reported by Sony [21]. A transfer technology of the TFT layers to the plastic was developed by Sony and Sony without the degradation of the device performance [22]. The drawback of this technology may be the productivity and manufacturing.

OTFT circuits have been reported on a glass, a polyimide, a high-temperature engineering polymer and a polyester film consisting of a single-transistor, smart-pixel and two-transistor invertors. Recently an active-matrix LCD was demonstrated using an organic thin-film transistor on polyester substrate [23]. The technology permits rugged, light-weight, flexible video displays to be built on plastic.

Fig 3. A display image of a 7-inch flexible LCD.

Table 6. The specifications of a 7-inch flexible LCD.

Display mode	Transmissive
Resolution	640 × 480
Aperture ratio	40 %
Brightness	100 cd/m^2
Color saturation	60 % (of NTSC)

Competition with Emissive Displays

TFT-LCD for mobile displays may be competed with AMOLED, but large LCD TV is competing with PDP in large-area >40”. AMOLED has quite simple structure compared with AMLCD because it does not have color filter, backlight unit and polarizers. The disadvantage for AMLCD is higher manufacturing cost compared with PDP. With the increase in the mother glass size, the large TFT-LCD can be similar cost or less than PDP. Recently, the price gap between LCD and PDP in 42” is less than 10%, so that the sale volume is almost the same between the two in display size of 40 inch level in Korea. Figure 4 shows the image of a world’s largest 82” TFT-LCD and its display specifications are summarized in Table 7. On the other hand, the image of world’ largest PDP is shown in Fig. 5 and its specifications are summarized in Table 8.

Fig 4. A display image of a 82-inch LCD.

Table 7. The specifications of a 82-inch LCD.

LC mode	Super-PVA
Panel size	1875 × 1080 × 45 mm
Resolution	1920 × 1080
Response time	< 8 ms
Color reproduction	92 %
Contrast ratio	1200:1
Brightness	600 cd/m^2
Viewing angle	180 ^{o}

Fig 5. A display image of a 102-inch PDP.

Table 8. The specifications of a 102-inch PDP.

Resolution	1920 × 1080
Contrast ratio	2000:1
Brightness	1000 cd/m^2

Conclusion

TFT-LCD became the winner for notebook and PC monitors. But in the digital society with high vision display, PDP and LCD are competing each other. The success of TFT-LCD in this competition may rely on the cost-down of LCD panel. For value-added display, LTPS TFT will continue to be developed until the TFT made of LTPS is similar to SOI TFT. The TFT-LCD on plastic, developed in 7 inch, can be a good solution of mobile applications.

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Author Biography

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