Influence of Product Architecture on the Competition Between LCD and PDP Technologies

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Abstract: The popularity of flat TVs began to reach its stride at the beginning of the 21st century, and the market size has expanded rapidly. The plasma display panel (PDP) technology was predominant initially, but the liquid crystal display (LCD) technology has presently overtaken PDP technology. Most of the actual conditions for the competition between LCD and PDP have not been clarified. In this study, our aim was to understand the factors because of which LCD overtook PDP in terms of the product architecture and to clarify the architecture's influence on the competition between LCD and PDP. The results showed that PDP and LCD have integral-type and modular-type architectures, respectively, and that this difference has had a big influence on the market competition between the two technologies.
Key Words: Product architecture; LCD; PDP.

1 Introduction

The popularity of flat TVs began to reach its stride at the beginning of the 21st century, and the market size expanded rapidly to replace cathode ray tube (CRT) technology and fill the newly expanding market for large-sized TVs of 40 inches or more. Among the flat TV technologies, the plasma display panel (PDP) technology was predominant initially, but liquid crystal display (LCD) technology has presently overtaken PDP technology. However, most of the actual conditions of the competition between LCD and PDP have not been clarified. Although many studies have been carried out on the LCD industry, most were related to its development or the competition between Japanese, South Korean and Taiwanese firms[1-5]; there has been no research aimed at clarifying the factors because of which LCD has overtaken PDP. The principles and structures of LCD and PDP are completely different, so a difference in product architectures seems to exist. We examined the influence of the product architecture on the competition between LCD and PDP and aimed to understand the factors because of which LCD has overtaken PDP in terms of the product architecture. Our findings show that there was a difference in product architecture between LCD and PDP that had a big influence on the market competition between LCD and PDP. This case study is a very important example because with the different product architectures fighting for hegemony in the same market (television) during the same time period, it is the optimal example for considering the influence of the product architecture on market competition.

2 Methodology

This study was conducted using statistical materials from the Fuji Chimera Research Institute, the Nikkei BP trade magazine (flat-panel displays), and LCD and PDP-related technical books. Data and reports published by the trade magazine were utilized for verification, as shown in Sections 3 and 5, and the product architecture analysis of LCD and PDP in Section 4 was conducted based on the description of the principles and structures in various technical books.

3 Competition Between LCD and PDP in the Flat TV Market

3.1 Share transition of LCD and PDP in the Flat TV Market

Figure 1 shows the transition of display shipment amounts according to size. Although PDP was predominant for all the sizes at the beginning of the spread of flat TV, LCD's share exceeded that of PDP in the 30-in domain in 2003, 40-in domain in 2006, and 50-in or more domain in 2008; at present, it has overtaken PDP. At the beginning of the spread of flat TV, PDP manufacturers claimed that PDP was superior to LCD in terms of both performance and cost [6-8] and thought that PDP and LCD could coexist around the 40-in domain from 32 in[9,10]. In other words, the competition between LCD and PDP in the flat TV market greatly upset the original assumptions of the PDP manufacturers.

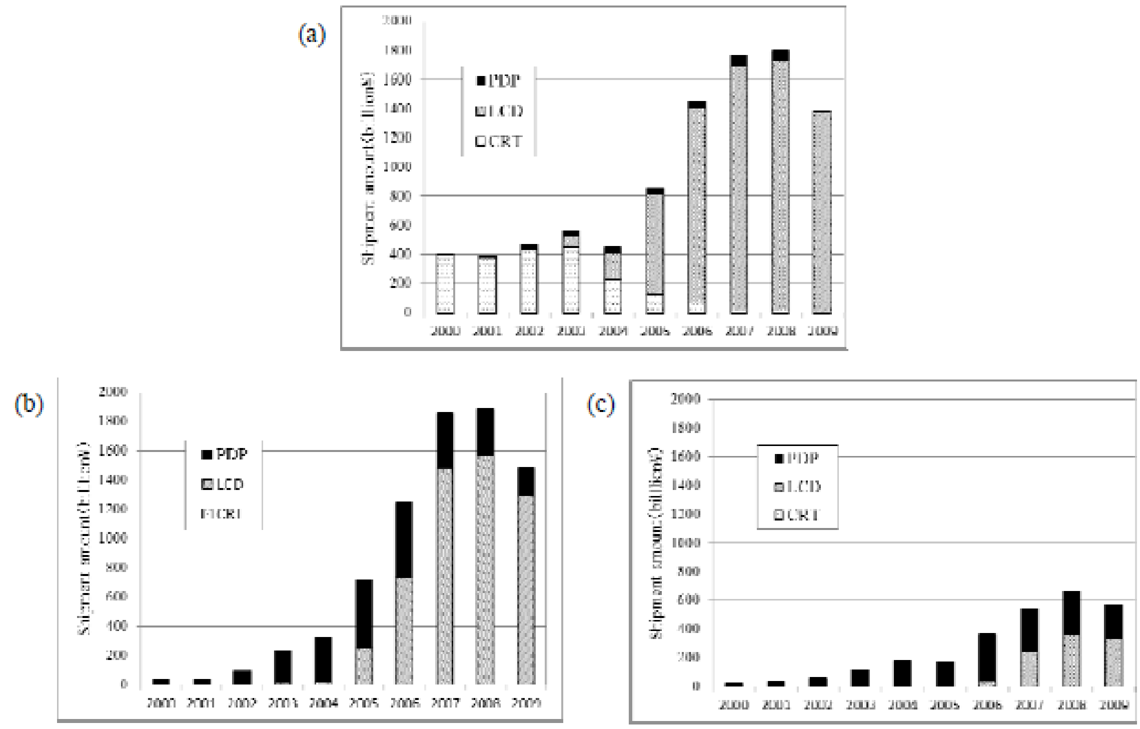

Figure 1 Amount-of-money Transition for Display Shipment Classified by Size: Levels of (a) 30 in, (b) 40 in, and (c) 50 in or more

Source: Fuji Chimera Research Institute (2001-2010) [11, 12, 13, 14, 15, 16, 17, 18, 19, 20]

3.2 Competition in Performance and Price

Table 1 shows the diagonal screen size and number of pixels of a maximum-size product in each size domain from 2001 to 2006. That table shows that PDP proceeded in size and LCD proceeded in the number of pixels, while PDP lagged behind LCD in the deployment of a full HD (1920 × 1080 pixels) product in the volume zone (levels of 30 and 40 in). While commercial production of 37-in full HD LCD was successfully deployed in 2003, PDP did not put 40-in full HD on the market until 2007. Although the PDP manufacturers fully recognized the necessity for full HD, the comments of Mr. Minsun Yoo of Samsung SDI clearly showed that PDP manufacturers lagged behind full HD development in the volume zone due to technical issues[21].

Table 1 Specification Transition of LCD and PDP Products (Size, Number of Pixels)

		2001	2002	2003	2004	2005	2006
LCD	50inches or more	—	—	55" 1920*1200	55" 1920*1080	57" 1920*1080	57" 1920*1080
	The level of 40 inches	—	42" 1366*768	46□ 1920*1080	47□ 1920*1080	47□ 1920*1080	47□ 1920*1080
	The level of 30 inches	—	37□ 1366*768	37□ 1920*1080	37□ 1920*1080	37□ 1920*1080	37□ 1920*1080
PDP	50inches or more	61□ 1365*768	63□ 1366*768	63□ 1366*768	80□ 1920*1080	102" 1920*1080	102" 1920*1080
	The level of 40 inches	42□ 1024*1024	42□ 1024*1024	46□ 1366*768	43" 1024*768	43" 1024*768	43" 1024*768
	The level of 30 inches	37□ 1024*1024	37□ 1024*1024	37□ 1024*1024	37□ 1024*1024	37□ 1024*1080	37□ 1024*1024

Source : Fuji Chimera Research Institute (2002-2007) [12-17]

Table 2 shows the results from when Mr. Jumpei Nakamura of the Japan Picture Quality & Technology Laboratory evaluated the flat TVs of each company using the same measuring method. The table clearly shows that with respect to quantitative (e.g., luminosity and contrast ratio) as well as qualitative evaluation, the image qualities of LCD and PDP were almost equivalent. Although LCD was initially inferior to PDP in image quality, LCD manufactures quickly enhanced the image quality and had reached almost the same level as PDP around 2005. Moreover, LCD consumed less power than PDP for all sizes (figure 2). Figure 3 expresses the transition of the unit prices of LCD and PDP modules. Although a strict comparison was difficult since the price is influenced by the size and number of pixels, the price of LCD quickly caught up to that of PDP and in 2006 was a little cheaper than PDP for the level of 30 in and almost equivalent to PDP on the level of 40 in. In terms of power consumption and the number of pixels (full HD), LCD was clearly superior to PDP; LCD is believed to have gradually overtaken PDP because of these dominances. Considering that ground digital broadcasting began in Tokyo, Osaka and Nagoya at the end of 2003, the delay in full HD of PDP was a significant adverse factor in its competition with LCD

Table 2 Image Quality Evaluation Results of FPD Television

Manufacturer		Panasonic	SONY	Panasonic	Sharp
Method		LCD	LCD	PDP	LCD
Size		32	40	50	32
Evaluation Item	Brightness	5	5	3	4
	Cotrast	5	5	5	5
	Viewing Angle	4	3	5	3
	Response Time	3.5	3	4	3
	Color gamut	5	5	5	5
	Color Reproducibility	4	4	4	4
	Gradation Characteristics	5	5	4	4
	Ringing	5	5	4	5
	Sharpness	5	4	5	5
	Smoothing	4	5	5	5
	Streaking	5	5	4	5
	Color Transient	5	5	5	5
	Afterimage	5	5	4	5
	Uniformity	4	4	4	4
	Noise	4	4	3	3
	The difference in an input system	4	5	5	4
Total Score		72.5	72	69	69
Measured Data	Maximum luminance (cd/m^2)	561	573	302	485
	Contrast Ratio	2672	1264	2745	744

Thus, betraying the PDP manufacturers' assumption, LCD quickly caught up to PDP in terms of both performance and price, and the two products were equal at around 2005–2006.

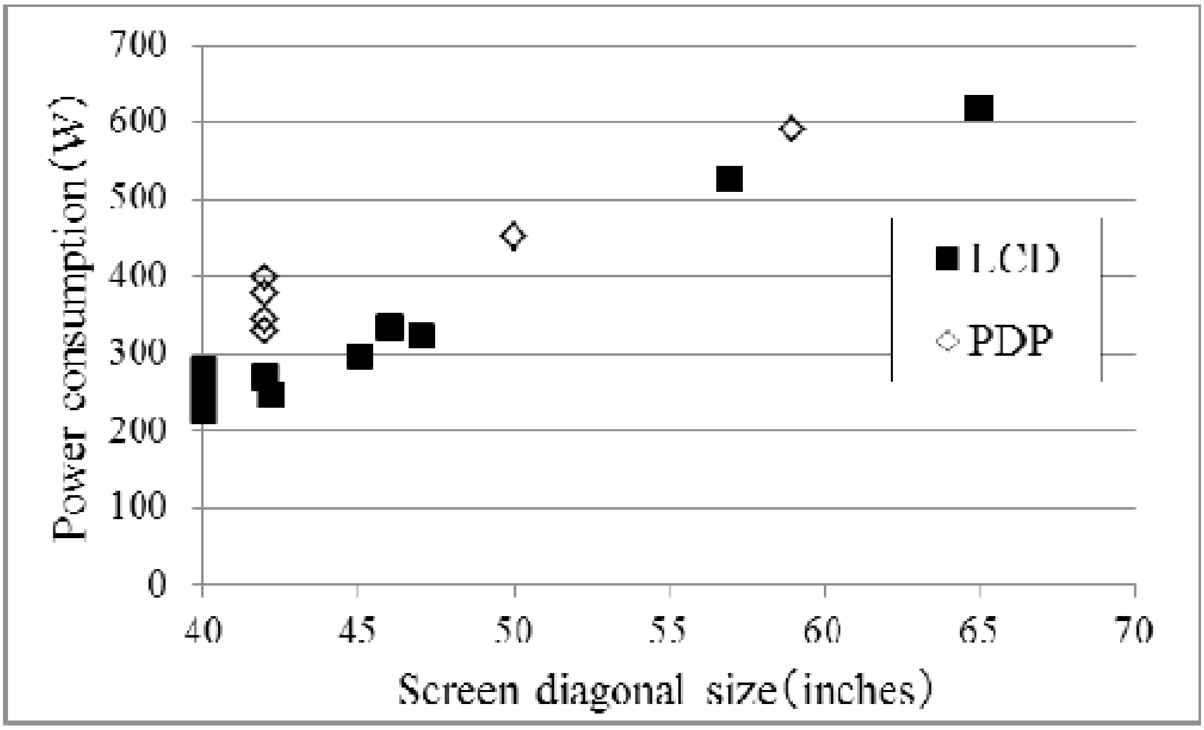

Figure 2 Power Consumption Comparison of LCD and PDP Television
Source: Tanaka (2006) p. 53 Figure 18 [23]
Original data: Data of Micro device display consortium (MDDPC)

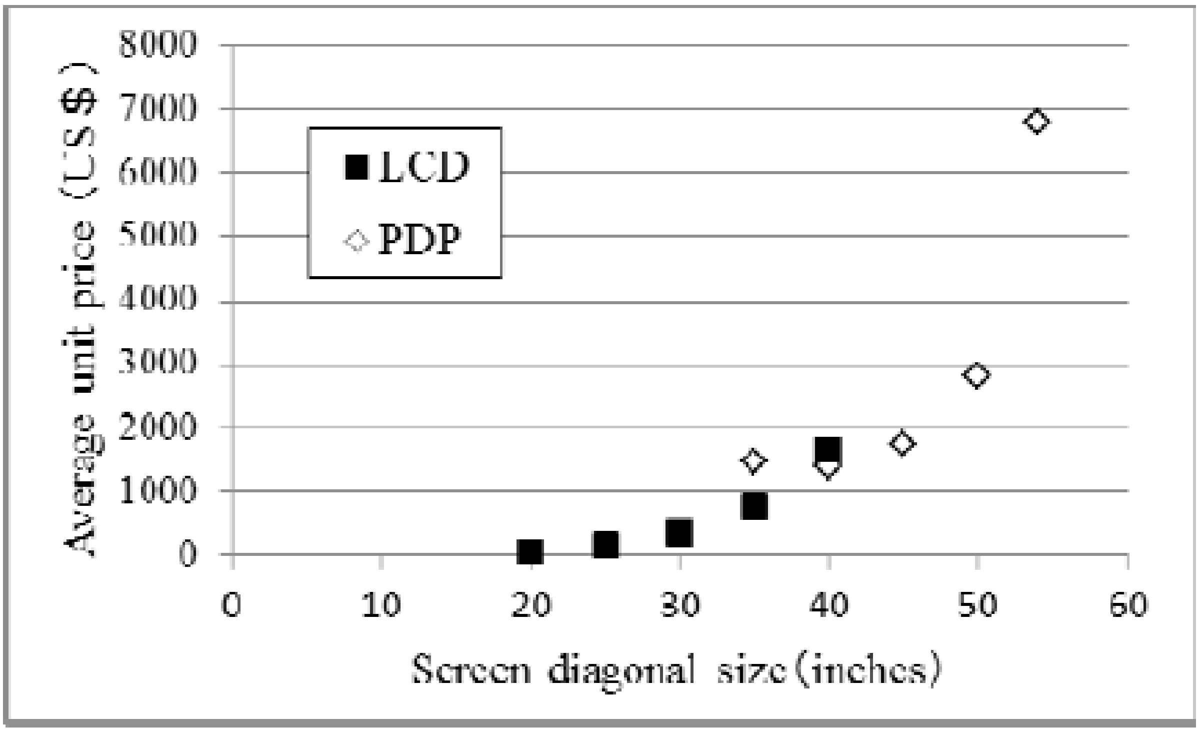

Figure 3 Price Comparison of LCD and PDP Television
Source: Tanaka (2006) p.45 Figure 7 [23]
Original data: Data of U.S. i-Suppli Corp.

4 Product Architecture Analysis of LCD and PDP

4.1 Fundamental function structure of display

The product architecture is the scheme by which the function of a product is allocated to physical components (PC). Ulrich defined the product architecture more precisely as (1) the arrangement of functional elements (FE), (2) mapping from function elements to physical components, and (3) specification of the interfaces among interacting physical components. Furthermore, he classified the product architecture as modular and integral. A modular architecture includes one-to-one mapping from functional elements in the function structure to the physical components of the product and specifies decoupled interfaces between components. An integral architecture includes complex (not one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components[24]. Generally, the top function element of a product is realized by uniting various lower-rank levels of functional elements[25]. Therefore, in order to determine the product architecture of a display in a strict manner, decomposing the functional elements of a display into lower rank levels to clarify the relations between each function element is necessary.

The electronic display (henceforth called "display") is defined as the component that displays information created or sent in the form of an electric signal in a visible form that can be discerned in terms of color and brightness. In order to change the information included in an input electric signal into visual information, a display requires the function of " electro-optical conversion," which changes an electric signal into optical information, and "addressing," which changes an electric signal into position information. Moreover, addressing is realized by "scanning" and "synchronization"[26]. Based on the argument above, the top function of a display is "displaying the information made or sent in the form of an electric signal in a visible form that can be discerned in terms of color and brightness." "Electro-optical conversion" and "addressing" can be regarded as functional elements of individual lower layers (FE1 and FE2, respectively); "color display" and "dimming" are contained in FE1, and "scanning" and "synchronization" are included in FE2. Although there are many kinds of displays, the abovementioned concept is followed for almost all displays. The differences in the kinds of displays of CRT, LCD, PDP, etc. appear as differences in layer function structures lower than FE1. Various kinds of displays compete to provide better performance in layer function elements or function structures lower than FE1. Therefore, this study focused on these lower layer function elements and function structures below FE1. Although other functions such as "protecting a structure" exist in a display, functions not directly related to displaying were not part of the scope of this study and disregarded.

4.2 Display principle and product architecture of LCD[27]

LCD is a display that uses the electro-optical characteristics of liquid crystal and is a non-emitting display type. As shown in Figure 4, LCD consists of two glass substrates and a backlight. A color filter (CF) is formed on a front glass surface, and the electrode—consisting of a thin film transistor (TFT) and gate, source, drain, and display electrodes—is formed on the surface of a backboard. One pixel consists of red, green and blue sub-pixels, and TFT is formed in every sub-pixel. CF bears a coloring function, and the electrode bears the role of transmitting the electric signal from a driving circuit to each sub-pixel.

Moreover, the alignment layer is formed on an electrode and CF, the space between the two glass substrates is filled with liquid crystal, and the polarizers are stuck on the back of the two glass substrates. The dimming function (optical shutter function) is realized by the liquid crystal, polarizer and alignment layer. The component bearing the optical shutter is called a liquid crystal cell. The backlight plays the role of a light source and consists of light sources such as a cold cathode fluorescent lamp (CCFL) and LED (light emitting diode), light-guide plate, diffusion film, light reflector and prism sheet.

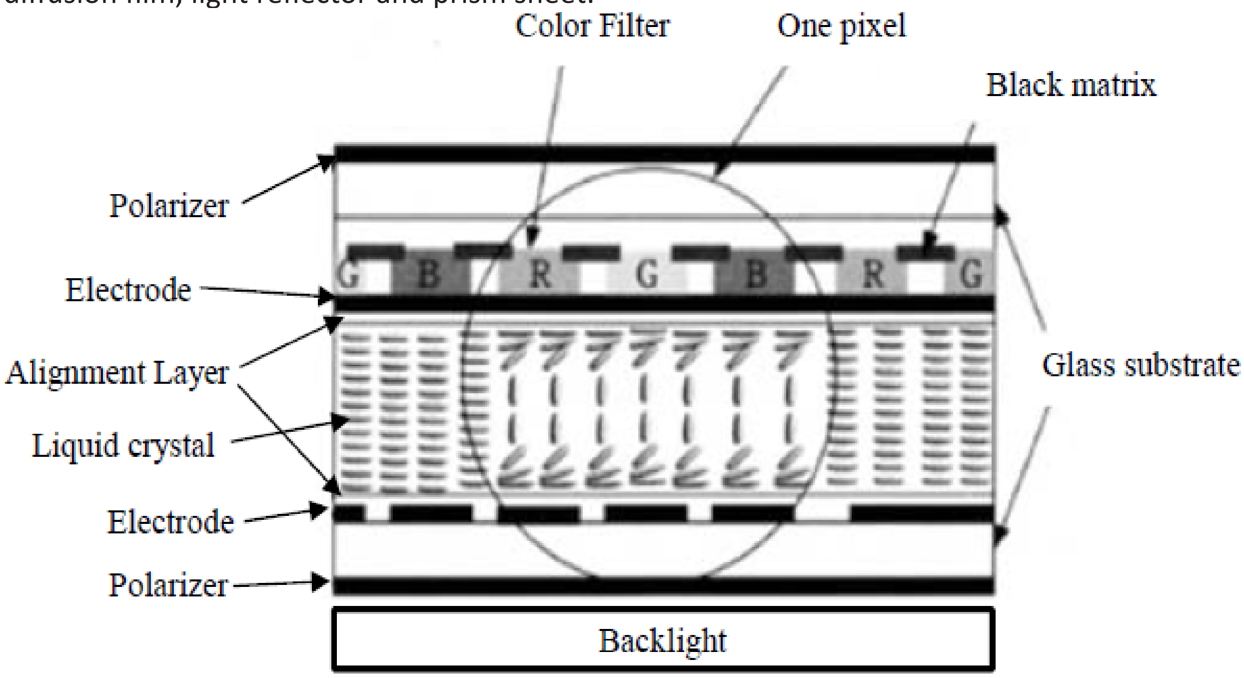

Figure 4 Structure of LCD
Source : Naemura (2004) p.93, Figure 2-40 [27]

We consider the function structure of LCD based on the argument in 4.1 and the display principle of LCD. In LCD, “the electro-optical conversion function (FE1)” is realized by three functions: “the function to transmit an electric signal to a sub-pixel (FE11);” “the function to color each sub-pixel red/green/blue (FE12);” and “the function to dim (adjust the brightness) each sub-pixel (FE13).” Furthermore, FE11 consists of “a function to change a picture signal into a driving signal (FE111)” and “a function to transmit a driving signal to a sub-pixel (FE112);” and FE13 consists of “a function to adjust a light transmission amount per sub-pixel (FE131)” and “a function to emit light (FE132).” On the other hand, “the addressing function (FE2)” is realized by two functions: “the synchronizing function (FE21)” and “the function to scan (FE22)”. In LCD, the bottom layer that does not need to be decomposed any further contains seven functional elements.*

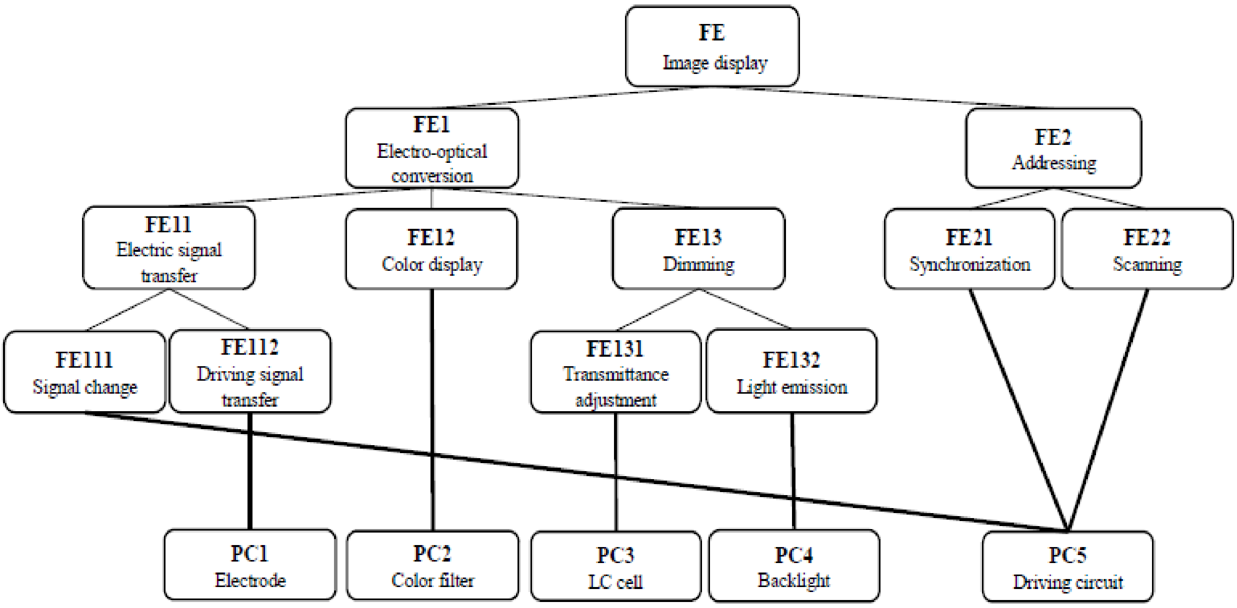

Figure 5 Function Structure of LCD and the Relations Between FEs and PCs

Next, we consider PCs corresponding to the FEs of the bottom layer. A picture signal is changed into the driving signal for the LCD in a driving circuit; it is transmitted to a display electrode through a gate electrode/source electrode/TFT/drain electrode, and voltage is impressed on a sub-pixel. Therefore, the driving circuit (PC5) bears the function of FE111, and the electrode (PC1) bears the function of FE112. The gate electrode/source electrode /TFT/drain electrode/display electrode are the parts that constitute an electrode. Moreover, CF (PC2) clearly bears the color display function FE12, and the liquid crystal cell (PC3) and backlight (PC4) bear the functions FE131 and FE132, respectively. In addition, the electrode, CF and liquid crystal cell are currently treated as separate PCs since they are completely different in function, although they have solid constructions.** On the other hand, since the synchronization and scanning are performed according to the directions of the driving circuit, the driving circuit (PC5) bears both functions FE21 and FE22.

The relations of FEs and PCs in LCD are shown in Figure 5. In LCD, the electrode bears only the transmitting function of the driving signal to a pixel, CF bears only the coloring function, the liquid crystal cell bears only the light adjusting function, and the backlight bears only the function of a light source. The relations between each FE and PC are clearly divided as one-to-one. Moreover, although interaction exists between the driving circuit and electrodes and electrodes and liquid crystal cell, there is no strong interaction between the other PCs. LCD appears to have a product architecture that is very close to a modular type based on the above information.

4.3 Display principle and product architecture of PDP[28]

PDP is a spontaneous light type display that uses plasma. The PDP structure is shown in Figure 6. The address electrodes covered with the dielectric layer are formed on a back glass substrate, and the partition (i.e., rib) is prepared parallel to the address electrodes on the dielectric layer. Moreover, red, green, and blue phosphor layers are applied to the inside of the rib. The scanning electrodes and sustain electrodes are formed on a front glass substrate, and they intersect perpendicularly with the address electrodes. The scanning electrode and sustain electrode are covered with the dielectric layer, upon which a protection layer is also formed. The discharge gas, which consists of helium, neon, xenon, etc., is enclosed between the front and back substrates. The discharge gas forms the plasma and bears the role of emitting ultraviolet rays. The protection layer bears the role of protecting the dielectric layer from high-energy ions. The rib specifies the domain of a cell, and each cell is equivalent to a sub-pixel.

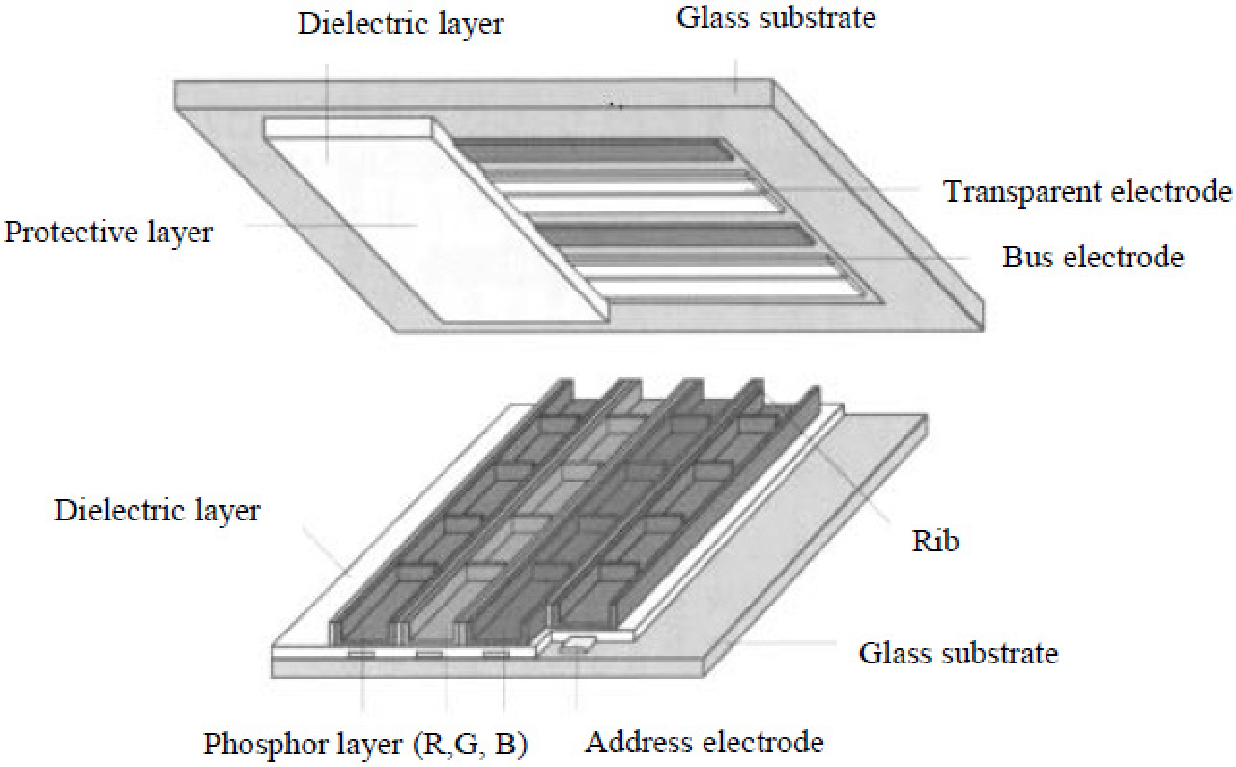

Figure 6 Structure of PDP
Source: The Advanced PDP Display Development Center Corporation (2006) p. 79[28]

The display principle of PDP is as follows. High voltage is impressed on a cell, and discharge plasma is generated. The collisions between electrons and discharge gas molecules are frequently repeated in the process. Energy is transmitted to the discharge gas molecule from an electron, and the discharge gas molecules become excited. When a discharge gas molecule returns from an excited state to a ground state, it emits ultraviolet rays. The fluorescent substance absorbs these ultraviolet rays. Red, green, and blue visible light are emitted depending on the kind of fluorescent substance, and various brightness levels and colors are obtained by additive color mixing. Moreover, the luminosity of a cell is adjusted by changing the frequency of luminescence within a definite period of time. In other words, the frequency of luminescence is increased to enhance the luminosity of a cell; conversely, the frequency of luminescence is decreased to reduce the luminosity. Adjustment of the luminosity in PDP is realized by repeating the same operation as the display of a color.

We checked the function structure of PDP based on the argument in 4.1 and display principle of PDP. In PDP, “the electro-optical conversion function (FE1)” is realized by the following three functions: “the function to transmit an electric signal to a sub-pixel (FE11),” “the function to emit red/green/blue light in each sub-pixel (FE12),” and “the function to adjust the frequency of luminescence in each sub-pixel (FE13).” Furthermore, FE11 consists of “a function to change a picture signal into a driving signal (FE111)" and "a function to transmit a driving signal to a sub-pixel (FE112)." FE12 consists of "the function to discharge in each sub-pixel (FE121)", "the function to emit ultraviolet rays in each sub-pixel (FE122)," and "a function to emit red/green/blue fluorescence in each sub-pixel (FE123)." FE121, FE122, and FE123 are a sequence of operations that cannot be used to realize a higher layer function (FE12) if one is missing. On the other hand, "the addressing function (FE2)" is realized by two functions: "the synchronizing function (FE21)" and "the function to scan (FE22)". In PDP, the bottom layer that does not need to be decomposed any further contains eight function elements.***

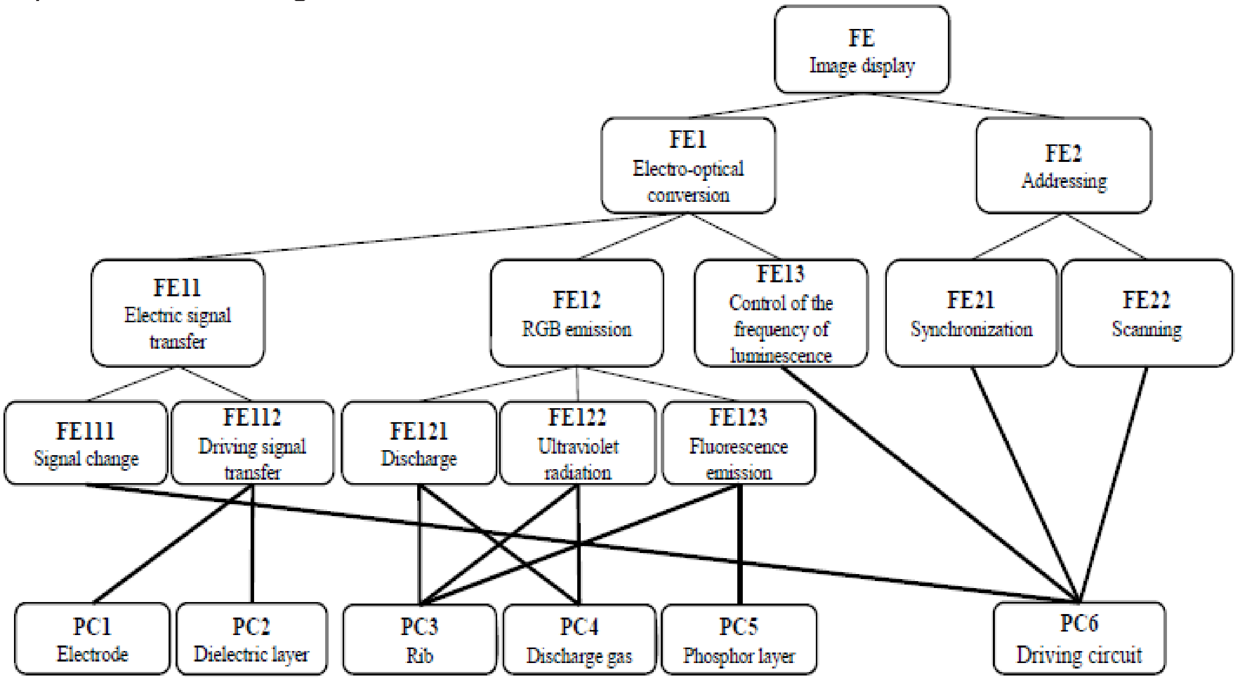

Figure 7 Function Structure of PDP and the Relations Between FEs and PCs

Next, we consider PCs corresponding to the FEs of the bottom layer. A picture signal is changed into the driving signal for a PDP in a driving circuit; it is transmitted to a sub-pixel through an address electrode/scanning electrode and sustain electrode, and voltage is impressed on a sub-pixel by collaboration of each electrode and a dielectric layer. Therefore, the driving circuit (PC6) bears the function of FE111, and the electrode (PC1) consisting of the address electrode/scanning electrode/sustain electrode and dielectric layer (PC2) bear the function of FE112. The address electrode, scanning electrode, and sustain electrode are parts of PC1. The rib (PC3) and discharge gas (PC4) both bear the discharge functions (FE121) and ultraviolet irradiance functions (FE122) in each sub-pixel. Furthermore, since the fluorescent substance absorbs the ultraviolet rays emitted from the discharge gas, and visible red/green/blue light is emitted, the function of FE123 is realized by the rib (PC3) and phosphor layer (PC5). On the other hand, control of the frequency of luminescence, synchronization and scanning are performed according to directions of the driving circuit, so the driving circuit (PC6) bears the functions of FE13, FE21, and FE22.

The relations of the FEs and PCs of PDP are shown in Figure 7. The corresponding relations between FEs and PCs are very complicated, and each PC is tied up by very strong interdependent relations. Thus, PDP appears to have integral-type product architecture.

5 Influence of Product Architecture on LCD and PDP Market Competition

As described in Section 3, LCD's rapid equaling of PDP's performance and price and the latter's development delay of full HD products in the volume zone were considered as factors that enabled LCD in overtaking PDP. In this section, we consider the influence of the LCD and PDP product architectures on the abovementioned factors.

Modular architecture contributes to optimization of local performance for a practical reason[24]. In fact, for LCD, which has modular-type architecture, the main characteristics can be improved by improving single components. For example, improvements in the liquid crystal cell can improve the response time and viewing angle dependence, and improvements in the backlight and CF improve the brightness and color reproducibility, respectively. Improvement in the color reproducibility and reduction in power consumption were realized by replacing the CCFL backlight with LEDs in recent years. This is also one example where the main characteristics were improved by improving the independent components. Moreover, the open trade environment for the major components of LCD was also considered to have contributed to the rapid catch-up of LCD in performance and price. The LCD manufacturers left the development of CF and backlight, which are major components, to external companies and purchased them as modules. The LCD manufacturers traded with two or more CF and backlight manufacturers, who also traded with two or more LCD manufacturers[29]. Although standards for the interface specifications of the CF and backlight do not exist in the LCD industry, the trade environment of the CF and backlight is nearly "open." Due to such an environment, the LCD manufacturers can outsource the development of major parts, utilize the suppliers' knowhow, and advance the detail design of major components independently and in parallel. Generally, the mitigation of the adjustment load between components, reservation of the independency of each module, reservation of the upgrade possibility for every module, promotion of innovation through a focus on individual modules, benefits from the merits of specialization, etc. are expected with modularization[30]. LCD harnessed the merits of such modularization and quickly caught up with PDP in terms of both performance and price.

On the other hand, intensification and regularization of the interface, which accompanies modularization, provided fixed restrictions on the maximum performance that can be attained by a system[30].This became a big issue when LCD competed with PDP, which has integral architecture. LCD reacted by the technique of strengthening the interaction between PCs. An improvement of the moving image quality of LCD is considered as a concrete example. In addition to the problem of a liquid crystal's own response, LCD had the problem that the moving image quality decreased due to the hold-type display of LCD[31]. The former problem was resolved by improving the liquid crystal cell and driving method, and the latter was improved by blinking backlight technology, which switched the backlight off after a definite period of time in one frame[32]. The technique to improve the color reproducibility by delicate adjustment of the CF and backlight and the technique to improve the contrast ratio by adjusting the backlight luminance for every fixed area according to the picture image[33] also strengthened the interaction between PCs. Thus, LCD strengthened the interaction between PCs (changing the interface rule), raised the maximum performance limit, and opposed PDP in the high-end zone. This modularity of LCD enabled it to strengthen or weaken the interaction between PCs as needed.

Next, we consider the influence of the integral nature of PDP on its development delay of the full HD products in a volume zone. Panasonic, which produced the full HD product of the 40-in level first, introduced cell miniaturization in the development of a 42-in full HD product, but reducing the width of the rib caused discharge interference between adjacent cells. Cross-talk was easily generated; the problem was resolved by the driving technique [34]. The phenomenon in which change in one component affects other components is a phenomenon peculiar to integral products. Under the influence of the integral nature of PDP, PDP manufacturers took a great deal of time to adjust PCs to each other, which caused them to lag behind in full HD development in a volume zone.

Generally, since the improvement speed of the performance can be increased by modularization, if the same amounts of time and cost are spent, the strategy of modularization can realize a relatively higher performance level. However, since the interface is fixed, unless the rules of the interface are changed, a performance beyond a certain constant level (p1) cannot be realized. On the other hand, if even time and resources sufficient for the integrated system can be supplied, an integral structure can exceed p1[30]. The important factor that determined the competition in the flat TV market was how fast the performance level required by customers was reached. LCD manufacturers took advantage of its modularity, improved the performance in a short period of time by improving individual components, and raised the highest performance level by strengthening the interaction between PCs (changing the interface rule) to finally enable LCD technology in overtaking PDP technology.

6 Conclusion

We examined the influence of the product architecture on the competition between LCD and PDP in order to understand the factors because of which LCD has overtaken PDP. Our results showed that PDP has integral-type architecture and LCD has modular-type architecture, which had a big influence on the market competition between LCD and PDP. The competition between LCD and PDP in the flat TV market is a very rare example for which product with different product architectures competed in the same market at the same period; we think that this clear example of the domination of the modular-type architecture is significant.

We are currently examining the influence of principles on product architecture formation and using LCD and PDP as an example. Results will soon be reported.

Note

* We mean a sufficient decomposition level to argue the product architecture.

** Ulrich pointed out that the distinct regions of an integrated circuit can be thought of as components even though they are not actually separate physical parts[24].

*** We mean that the decomposition level is the same as that for LCD and is sufficient to evaluate the product architecture.

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